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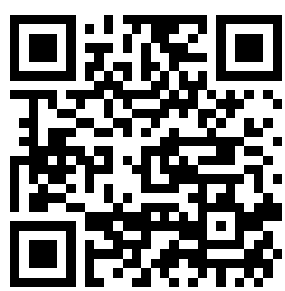

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AUTOMATIC TRACKING RADAR REPAIRMAN

(AFSC 30353)

Volume 3

Automatic Tracking Radar Principles

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Preface

THIS VOLUME OF CDC 30353 is comprised of seven chapters discussing the principles of the radars in our career field. The objective of this volume is to acquaint you with the fundamental principles, *not* to teach you the functional operation of any particular radar set.

The seven chapters in this volume cover the following systems: automatic tracking radar, transmitting, receiving, range, antenna positioning, presentation, and identification equipment.

Please note that in this volume we are using the singular pronoun *he, his,* and *him* in its generic sense, not its masculine sense. The word to which it refers is person.

Foldouts 1 through 3 are printed and bound in the back of the volume. When you are referred to one of these foldouts in the text, please locate it in the back of the volume.

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Material in this volume is technically accurate, adequate, and current as of August 1976.

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NOTE: In this volume, the subject matter is developed by a series of Learning Objectives. Each of these carries a 3-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see if your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Automatic Tracking Radar Systems

THE PURPOSE OF RADAR is to extend man's sight and make visual intelligence possible at night and in cloudy weather. A radar system may be used for any operation that requires a knowledge of the range, azimuth, and/or height of a target. A pulse-modulated system is often used because of the large power output that may be obtained with relatively small equipment.

A radar system may be either ground-based or airborne; it may survey a complete circle or just a sector of the area around its site. Radar systems in use today vary greatly as to the details of operation and use.

1-1. Basic Radar Principles

A brief review of the basic principles of radar will enable you to better understand the operation and maintenance of the various radar systems used in the Automatic Tracking Radar career field today.

400. Identify the blocks in a diagram of a basic radar system and state the purpose of each block.

A basic radar system consists of six functional blocks. The choice of details and specific circuits used will depend upon the particular use of the system.

A functional block diagram of a basic radar system is shown in figure 1-1.

- The power supply, which furnishes all AC and DC voltages necessary for the operation of the system components.
- The transmitter, which generates the radio-frequency (RF) energy in the form of short, powerful pulses.
- The antenna system, which accepts the RF energy from the transmitter, radiates it in a highly directional beam; receives any reflected RF energy (echo); and passes this energy to the receiver.
- The receiver, which amplifies the weak RF pulses received as echoes from a target and changes them to video pulses to be sent to the indicator.
- The indicator produces a visual indication of the range, azimuth, or elevation of the received targets.
- The timer (also known as the synchronizer) supplies the signals that time the transmitted pulses, indicator trace, and the time of operation of other related circuits in the system.

The very nature of radar and its uses requires exact timing of all operations in the system.

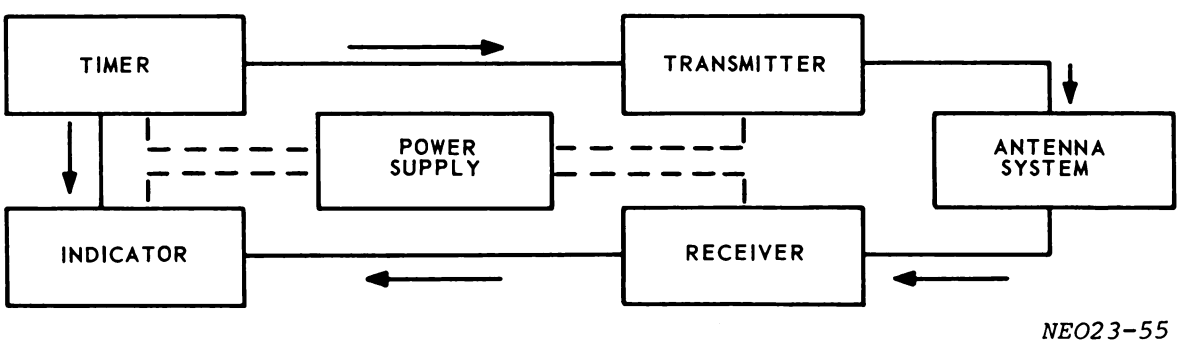

Figure 1-1. Basic radar system functional diagram.

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Exercises (400):
1. Label each block in figure 1-2.

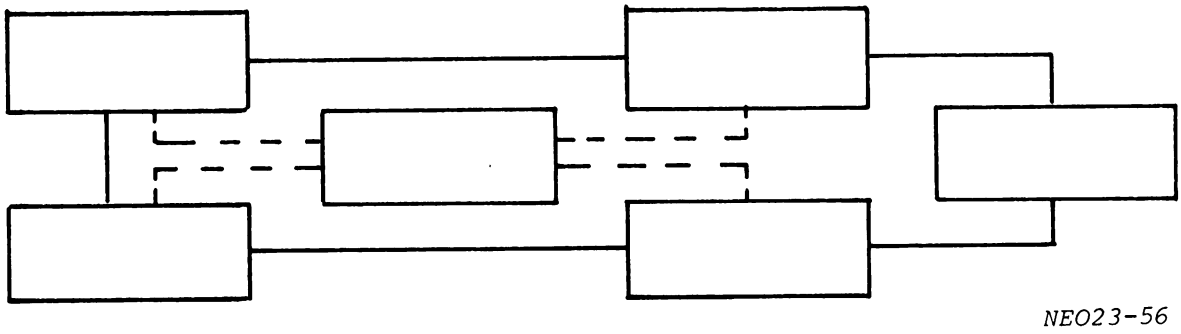

Figure 1-2. Basic radar system functional diagram (objective 400, exercise 1).

2. State the purpose of each block in figure 1-2.

401. State the principle on which radar operates and describe selected radar characteristics.

When a radar signal is emitted by a transmitter, radar waves, like light and sound waves, travel out in all directions and are reflected by any object that they strike. On striking the object, components of the wave are reflected and also travel in all directions. Some of the reflected waves return to the site of the transmitter originating them, where they are picked up by the receiver, provided it is kept tuned to the correct frequency.

The radar signal emitted by the transmitter can be controlled in duration and direction, like light and sound waves. This provides the ability to locate specific objects in space through the use of radar signals.

This explanation sounds quite simple, but there are, of course, some problems to solve. The first probem is one of a powerful transmitter and receiver operating on the same frequency. In order for the receiver to detect the reflected signal and thus indicate the presence of the target, the transmitter signal must be prevented from affecting the receiver.

The second problem is measuring distance. If a continuous, constant-frequency signal were transmitted, it would be impossible for the receiver to distinguish between various echoes at different distances, for they would all be alike. Thus, some means must be provided to eliminate the problems involved in using constant transmissions.

The pulse modulation system of detection is employed in most radar sets. In this system, the transmitter is turned on for short periods and off for long periods. During the period when the transmitter is turned on, it transmits a short burst of RF energy called a pulse. When a pulse strikes any object, part of the reflected energy is returned to the receiver, where it is displayed on the screen of a cathode-ray tube. Since the transmitter is turned off after each pulse, it does not interfere with the receiver as would be the case if a constant transmitted signal were used.

Complete location of an object in space by radar pulses depends upon two factors: the range and direction, including both the azimuth and elevation directions, of the target.

The successful use of a radar set depends primarily upon its ability to measure distance in terms of time. When radio energy is radiated into space, it continues to travel with a constant velocity. Its velocity is that of light, or about 186,000 statute miles per second or 161,750 nautical miles per second. In more useful terms, radio waves travel a nautical mile in 6.18 microseconds. They travel a radar mile; that is, a go-and-return mile, in 12.36 microseconds.

This constant velocity is used in radar to determine the distance, or range, of a target by measuring the time required for a pulse to travel to a target and return.

Two dimensions must be considered in determining the direction of a target. One is azimuth, which is the relative horizontal direction of the target with respect to some direction reference expressed in degrees. For example, this direction may be expressed with reference to true north if the radar set is a ground installation, or to the heading of the aircraft if the set is airborne. The other dimension is elevation, which, like azimuth, can also be expressed in degrees. Elevation expresses the angular degrees that the target is above or below the radar set.

The determination of azimuth and elevation depends upon the directional characteristics of antennas and antenna arrays. Antennas will be discussed later.

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Exercises (401):

1. What is the basic operating principle of all radar?

2. Does a radar system measure range directly?

3. What characteristics of radio waves make radar possible.?

4. What is the time in microseconds of a radar mile?

5. What two dimensions must be considered to determine the direction of a target?

6. How are azimuth and elevation of a radar target normally expressed?

7. How does a pulse modulation radar system determine range?

1-2. Uses of Automatic Tracking Radar Systems

It is almost impossible to understand fully the purpose and function of a carburetor without some knowledge of the gasoline engine with which the carburetor operates. This idea applies to automatic tracking radar systems as well. You may learn the intricacies of a tracking radar, but without an understanding of the overall system and its uses, you cannot realize the total importance of the role a tracking radar plays.

402. Given the descriptions and uses of automatic tracking radar systems, match each description with the proper use.

The autotrack system is designed for use in radar bomb scoring (RBS), close support bombing (CSB), and an electronic warfare (EW) environment. We will discuss each of these uses separately.

Radar Bomb Scoring. In RBS application, the autotrack system tracks an aircraft over an assigned target to score a simulated bomb drop. The aircraft crew furnishes the autotrack system crew with bomb drop data. This data is used in conjunction with the aircraft ground track, ground-speed, altitude, drift correction angle, and other related aircraft data to determine whether or not the bomb would have hit the target had one actually been dropped. If a miss is determined, the ground crew furnishes the error to the aircrew. This type of operation is designed for the training of Strategic Air Command (SAC) bomber crews.

Close Support Bombing. In CSB and missile guidance application, the procedure used in RBS is reversed. The ground crew furnishes the aircrew or missile control systems with all necessary information to guide the aircraft or missile to an assigned target. This information is furnished in the form of verbal commands or coded pulse commands. Thus, the aircraft or missile is guided to a target area; the aircraft is told exactly when to release the bomb load; or the missile is signaled when to go into terminal dive.

Electronic Warfare Environment. The automatic tracking system is used to train aircrews in simulated electronic warfare environments. It provides the pilot in fighter aircraft and the electronic warfare officer in bomber aircraft with training in recognizing radar signals during missions. It also allows him to practice jamming the signals from the radar system.

Exercises (402):

1. Match the descriptions in column A with the appropriate uses in column B by writing the correct letter in the blank provided. Uses may be used more than once.

Column A	*Column B*
___ 1. Permits the pilot or EWO to practice jamming signals from radar systems.	a. Radar bomb scoring.
___ 2. Ground crew directs the aircrew to an assigned target.	b. Close support bombing.
___ 3. Aircrew furnishes the ground crew with bomb drop data.	c. Electronic warfare environment.
___ 4. Ground crew informs the aircrew when to release the bomb.	
___ 5. Ground crew furnishes the aircrew with the error when the target is missed.	
___ 6. Provides aircrew with training in recognizing radar signals.	

1-3. Description of Basic Automatic Tracking Systems

Although this course presents material to you from a principle-centered approach, the following discussion is centered around one of the systems used in the field. Many of the components covered in this section are common to other autotrack systems, such as the AN/MSQ-1, AN/MSQ-2, AN/MSQ-1A, AN/MPQ-T2A, AN/MSQ-39, AN/MSQ-96, and AN/MSQ-35; most of the components, however, are found in the AN/MSQ-77.

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403. Identify the type of scanning described in selected statements.

Tracking Radar. The type of scanning system used for tracking radar generally determines the name given the system, such as *conical-scan* or *monopulse.* First, let's consider the basic operation of a conical-scan system.

Conical scanning. In conical scanning, the radar beam is made to describe the shape of a cone in space. The apex of this cone is located on the antenna and the cone is offset a small angle from the axis of the antenna. (See fig. 1-3.) The rotating beam overlaps, creating an effective beam width in the center of the scan. A target in this area reflects a constant amplitude return back to the radar from the beam as it rotates through a complete cycle; and the radar is said to be "locked on" to the target. If the target moves out of the effective beamwidth area, returns of varying amplitudes are reflected back to the radar as the beam rotates. A comparison of the signal strengths creates an error signal and causes the antenna drive unit to move the antenna in the direction of the strongest return.

Monopulse. The monopulse radar is a target-tracking radar system that obtains sufficient information from each transmitted pulse to update its computers and reposition its antenna. Instead of scanning a single beam, the radar uses a minimum of four separate beams which transmit together but receive independently. (See fig. 1-4.) By comparison of the energy returned in the beams, azimuth and elevation corrections can be made. This system has the ability to track even though there is a large amount of pulse-to-pulse fading.

Exercises (403):
Name the type of scanning described in each of the following statements.

1. The tracking radar system that transmits a rotating cone-shaped beam.

2. This radar system compares the relative signal strengths of successive reflected returns.

3. This radar system derives target position data from a single radiated pulse.

4. This radar system transmits four simultaneous beams and receives the reflected signals independently.

5. This radar system can track a target even though there is a large amount of pulse-to-pulse fading.

404. State the purpose of the analog computer.

In most radar systems, the automatic tracking radar system used is tied directly to an analog computer.

Analog Computer. The computer accepts range, azimuth, and elevation information from the radar. This information is received in a three-dimensional form (polar) and converted to a two-dimensional form (rectangular) for display on the plotting board. It also solves problems with reference to ballistic characteristics for scoring bombing missions on predetermined targets.

Exercise (404):
1. What is the purpose of the analog computer?

405. State the purpose of the identification, friend or foe/selective identification feature (IFF/SIF) system.

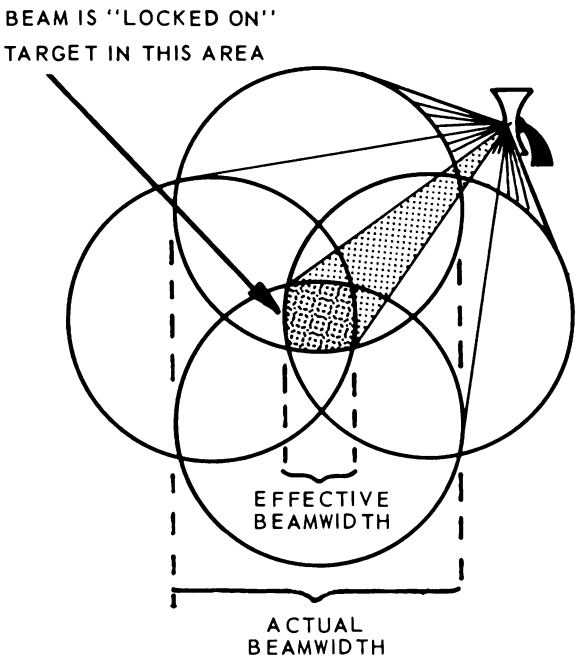

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Figure 1-3. Conical scan radar.

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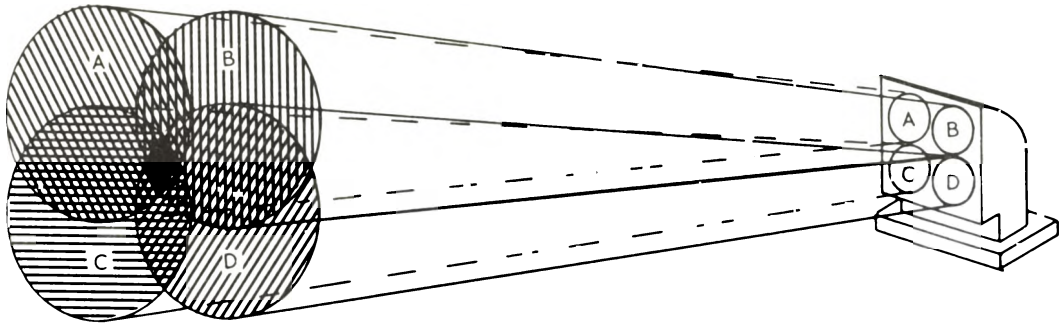

- AZIMUTH ERROR – = (A+C) – (B+D)

  IF (A+C) – (B+D) = 0 (NO ERROR)

- ELEVATION ERROR – = (A+B) – (C+D)

  IF (A + B) – (C + D) = D (NO ERROR)

IF A = B = C = D – THE TARGET IS CENTERED

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Figure 1-4. Monopulse radar.

IFF/SIF. The identification, friend or foe/selective identification feature (IFF/SIF) system provides the radar operator with the identification and location of friendly aircraft within the operational range limits of the autotrack system. This information is especially useful in congested flying areas where one particular aircraft must be distinguished from others.

Although the IFF/SIF system is a separate radar, it is normally synchronized with the tracking radar trigger when it is used with autotrack systems. The IFF/SIF return signals are displayed on the plan position indicator (PPI).

Exercises (405):

1. State the purpose of the IFF/SIF system.

2. When is the information provided by the IFF/SIF system most helpful?

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Transmitting Systems

THE TRANSMITTER and receiver systems supply the radar information that is presented on the radar indicators. For each of these systems, the characteristics are determined by the purpose of the radar set. We have chosen the transmitter system as a convenient starting point and will examine its performance characteristics, circuits, and maintenance problems.

2-1. Principles of Systems Design

Among the more important characteristics of a transmitter are the methods of RF generation, the choice of operating frequency, the level of output power, and the duration and shape of the output pulse. Many of these are beyond the control of the maintenance man. Nevertheless, your insight into the what and why of transmitter characteristics will be an asset when you are troubleshooting a radar transmitter.

406. Given a list of the factors that affect transmitter design, identify the definition of each factor.

Timing Relationships. Certain characteristics of the inputs and outputs from a pulsed radar transmitter are shown in figure 2-1 and bear repeating as a preliminary to greater detail. Among these are:

a. PRF or pulse-recurrence frequency is a figure representing the number of triggers or pulses per second applied into a radar transmitter. The basic frequency of these pulses is determined by the system timing unit.

b. PRT or pulse-recurrence time is the interval from the start of one pulse to the start of the next, usually measured in microseconds, and is the reciprocal of PRF. That is,

$$\text{PRT}(\mu\text{sec}) = \frac{1 \times 10^6\ \mu\text{sec}}{\text{PRF}}$$

In some systems, the time interval varies in a programmed sequence called a staggered PRT.

c. PW or pulse width is the duration in microseconds of the pulse into the transmitter. It is the input trigger converted by the modulator into a high-voltage square wave of short duration.

d. Rest time is the time between transmitter pulses, in figure 2-1, during which received echoes are processed by the receiver.

e. Peak power is the instantaneous power level generated during the time that the pulse is applied to the magnetron. It is mainly determined by the amplitude of high voltage to the modulator.

f. Average power is peak power averaged over the entire PRT. This is the power measured by most test equipment.

g. Duty cycle is a decimal figure that represents the portion of the total PRT occupied by the pulse width.

Exercise (406):

1. Match the factors in column A with the appropriate definitions in column B by writing the correct letter in the blank provided. Definitions may be used once or not at all.

Column A	*Column B*
_____ 1. Pulse width.	a. Instantaneous power level generated when the pulse is applied to the magnetron.
_____ 2. Pulse-recurrence time.	b. Time interval from the start of one pulse to the start of the next.
_____ 3. Rest time.	c. Represents the portion of the total PRT occupied by the transmitted pulse.
_____ 4. Peak power.	d. Power measured by most test equipment.
_____ 5. Average power.	e. Time between transmitted pulses.
_____ 6. Duty cycle.	
_____ 7. Pulse-recurrence.	

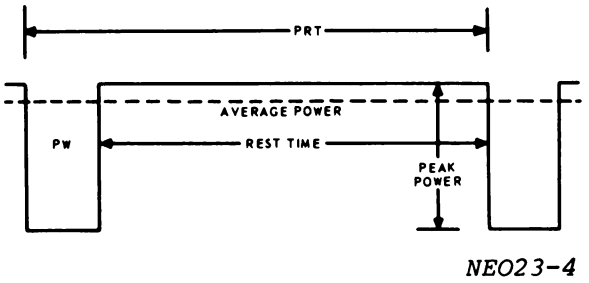

Figure 2-1. Pulse characteristics.

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f. Duration of the transmitted pulse.
g. Number of pulses per second applied to the transmitter.
h. Determines the amplitude of the high voltage applied to the modulator.

407. State the effect of a given pulse width and PRT upon peak power, duty cycle, average power, minimum range, maximum range, and range resolution.

Pulse Width and PRT. The pulse width and PRT of a radar system are governed by its particular application. Both quantities can be varied independently and have different effects upon the radar performance characteristics. As a point for beginning, realize that neither one determines peak power. This latter quantity varies with high-voltage input. However, average power is the product of peak power multiplied by duty cycle. Duty cycle is directly determined by both pulse width and PRT. The figure for duty cycle can be computed by dividing the PRT into the pulse width. To illustrate these points, consider a radar system using a pulse width of 0.7 microseconds, a PRT of 909 microseconds, and peak power of 600 kW. Then:

$$\begin{aligned} \text{Duty cycle} &= 0.7\ \mu\text{sec} \div 909\ \mu\text{sec} \\ &= 0.00077 \\ \text{Average power} &= 600\ \text{kW} \times 0.00077 \\ &= 0.462\ \text{kW or 462 watts} \end{aligned}$$

Pulse width also affects other qualities. One of these, minimum range, is the sum of pulse width and TR (transmit-receive) recovery time. The total establishes the shortest distance from the radar at which a target can be detected.

Range resolution—the ability of a radar to distinguish between two targets at the same azimuth—is in direct proportion to the width of the RF pulse in free space. A narrow pulse gives superior resolution. In autotrack radars, we must be able to distinguish between the returns of two targets very close together. The pulse width of track radars must therefore be very narrow. This requirement does not exist in most search radars. The pulse widths with which we are concerned range from 0.25 to 0.8 μsec in duration. Let's see how these two pulse widths affect range resolution.

If the transmitter pulse is 0.25 μsec wide, the pulse itself represents 42 yards. This means that targets within 42 yards of each other will all be contained within the same reflection and appear as a single target. In other words, the range resolution of the set is 42 yards. Now let's take the upper limit. If the pulse is 0.8 μsec wide, targets within 135.7 yards of each other will appear as a single target. The 0.25 μsec-wide pulse will, therefore, provide 3.2 times (320 percent) better range resolution that a pulse width of 0.8.

Exercises (407):

1. If the PRF is switched from 5500 PPS to 1833 PPS, what is the effect upon

   a. duty cycle?

   b. average power?

   c. maximum theoretical range?

2. Ignoring other considerations, what would be the minimum range when a 1-microsecond pulse is used?

3. Which produces superior range resolution: a 0.18-μsec pulse or a 0.7-μsec pulse?

2-2. Basic Transmitter Operation

The block diagram shown in figure 2-2 is typical of an autotrack transmitter using a magnetron. All blocks shown except the trigger-generating circuits and antenna components are covered in this chapter.

408. Given a list of specific transmitter components, identify their respective functions.

Basic timing is established by the positive trigger outputs of the system timing unit or synchronizer. One of these triggers is routed to the trigger amplifier for amplification. This is necessary because the amplitude of the input trigger is not of itself large enough to drive the thyratron in the modulator. Most large thyratrons must have triggers several hundreds of volts in amplitude for ionization.

The high-voltage power supply (HVPS) produces the DC voltage for the pulse-shaping circuit in the modulator with 8 kV a typical figure. The pulse-shaping circuit almost always consists of a charging circuit, a pulse-forming network (PFN), and the thyratron. The discharge of the PFN through the thyratron establishes the pulse width. The modulator output pulse, coincident with trigger time, is applied through a pulse transformer to the magnetron cathode. This high-voltage negative pulse causes the magnetron to oscillate throughout the duration of the pulse. The RF

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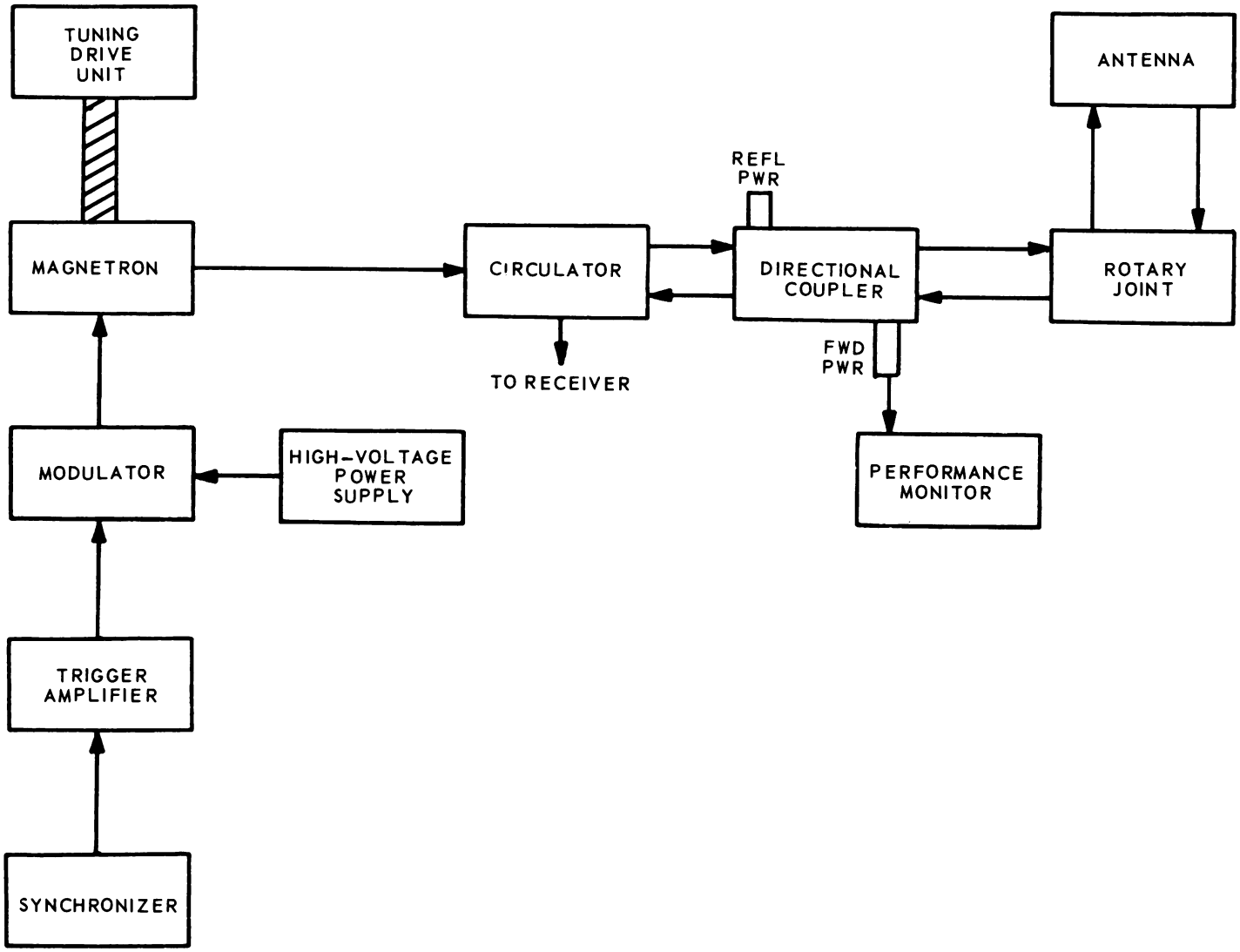

Figure 2-2. Transmitter block diagram.

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is coupled into the waveguide through a transition device. The circulator determines the direction of the energy flow. Transmitted RF is routed to the antenna; whereas, echo energy passes to the receiver.

Other elements shown serve special purposes. The directional coupler permits sampling or insertion of RF for test purposes. The tuning drive unit permits you to adjust the transmitted frequency. The rotary joint is a transition device between fixed waveguide and a rotating antenna.

Exercises (408):

1. Match specific transmitter components in column A with their respective functions in column B.

Column A	*Column B*
____ a. Trigger amplifier.	1. Produces RF pulse.
____ b. High-voltage power supply.	2. Couples fixed waveguide to antenna.
____ c. Pulse-shaping circuits.	3. Controls direction of energy.
____ d. Circulator.	4. Produces 8 kV.
____ e. Directional coupler.	5. Charging circuit, PFN, thyratron.
____ f. Rotary joint.	6. Samples RF for test purposes.
____ g. Tuning drive unit.	7. Adjusts transmitter frequency.
____ h. Magnetron.	8. Drives the modulator thyratron.

2. What is the relationship between input trigger and output RF?

3. Where is the high voltage used in the modulator circuit?

4. Which component provides connection for radar test equipment?

409. State the function of selected items shown on a block diagram of a line-type modulator circuit.

A number of methods have been used to produce the high-voltage pulses to the transmitter. There are two types of modulators used in autotrack radars: the line type and hard-tube type. First, we will discuss the operation of the line-type modulator.

Line-Type Modulator. The most characteristic component of the line-type modulator is the hydrogen thyratron. It is a gas-filled tube that acts as a switching device. Switching to the ON state occurs each time that a system trigger is amplified and applied to the grid of the thyratron. When this occurs, the discharge path of the energy storage unit (usually a PFN) is closed and a high-voltage pulse is applied to the load. The load is the magnetron and the RF assemblies beyond it. The transfer of pulse energy between PFN and magnetron is through a pulse transformer.

After PFN discharge, the thyratron switch "opens" and circuit recharging occurs. The charge path is shown in figure 2-3. Current flows toward the positive potential of the HVPS. The charging choke is part of a resonant network that charges the PFN to twice the applied voltage while awaiting the arrival of the next trigger.

Exercises (409):

Refer to figure 2-3.

1. What is the function of the switch tube used in a modulator circuit?

2. What is the function of the PFN?

3. Why is a charging impedance circuit used?

410. Identify the characteristics of the thyratron circuit.

Hydrogen thyratrons. Figure 2-4 contains the basic elements of the line-type modulator. The thyratron tube is essential to its operation. It has near-zero impedance when switched on (ionized) and can handle very high-power levels. It has certain peculiarities relating to its content of hydrogen gas. For example, high voltage on its plate will not of itself cause conduction. A voltage of sufficient potential to ionize gas must first be applied to the grid. Then, almost instantly, the

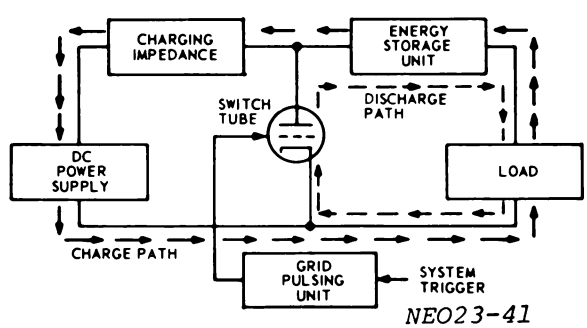

Figure 2-3. Line-type modulator.

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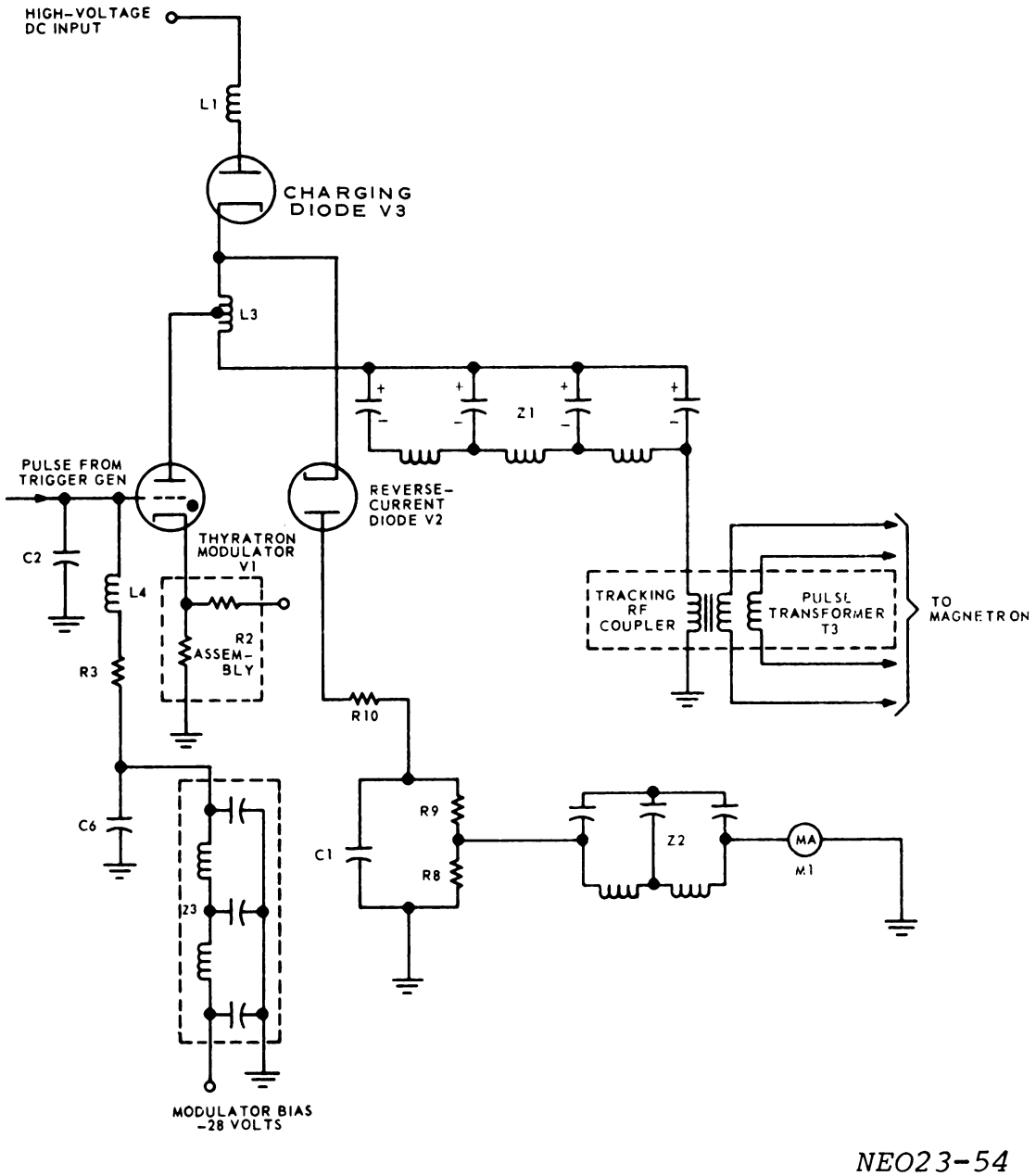

Figure 2-4. Modulator, simplified schematic.

tube switches to full conduction. At that point, the grid has lost all control. The only way to turn the tube off is to deionize it by removing the plate voltage.

Exercises (410):
Identify the following as true or false by marking with a T or F.

_____ 1. Ionization increases thyratron impedance.
_____ 2. The thyratron can be fully ionized in the absence of high voltage.
_____ 3. The trigger from the trigger amplifier overcomes tube bias.
_____ 4. Triggers turn the thyratron switch on and off.
_____ 5. Deionization occurs when high voltage is removed.

411. State the reaction of a thyratron to changes of gas pressure and reservoir voltage above and below the optimum level.

Hydrogen reservoir. Hydrogen is most often used in thyratrons in preference to other gases because of its rapid ionization and deionization. In addition, since

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hydrogen has the lightest ion, cathode erosion due to ion bombardment is reduced. The hydrogen content is quite critical and varies somewhat over the lifespan of the tube. For this reason, large hydrogen thyratrons contain a capsule reservoir of a material (titanium hydride) that releases or absorbs hydrogen depending on its temperature.

As the thyratron tube ages, its characteristics change, including the voltage required to maintain correct gas pressure. Fortunately, observation of the thyratron in operation can tell much about the level of capsule voltage. If the tube shows evidence of flashing or erratic firing, the gas pressure may be too high. The voltage should then be reduced in 1/10-volt increments, allowing at least 5 minutes between changes, until stable operation is achieved. If the gas pressure is too low, the plate resistance increases, causing the plate to overheat or even to glow cherry red. If operated in this condition, the thyratron will probably be damaged or destroyed. So, if a glowing plate is noted, remove high voltage, increase the capsule voltage, and wait several minutes before reapplying high voltage.

Exercises (411):

1. Although the capsule voltage is set to the value stamped on the tube, the thyratron plate glows red when operating. What can be done to correct this condition?

2. What visual conditions indicate excessive gas pressure in a thyratron?

412. Draw and label a waveform diagram showing the normal charge and discharge waveform of a PFN and the waveform that occurs when the PFN is not pulsed.

Pulse-forming network. The action of a charging circuit is similar to a series-resonant tank circuit. However, a capacitor is not satisfactory as a storage device, because its discharge waveform is exponential and will not produce the ideal rectangular pulse. Futhermore, the trigger to the grid of a thyratron can turn it on, but can control neither the shape nor duration of the output. The solution of these problems lies in the controlled discharge characteristics of the PFN.

The most satisfactory PFN is the delay line or artificial transmission line composed of capacitors and inductors as in Z1 of figure 2-4. It is series-resonant with L1. If V3 were removed and replaced by a piece of wire and high voltage applied in the absence of a trigger, the combination of L1 and Z1 would oscillate as in figure 2-5, A. The sine wave is the charging waveform of the PFN. Note that the first peak reaches twice the applied high voltage. Subsequent cycles will decrease in amplitude until they eventually dampen out to the level of the applied high voltage.

If the trigger were applied to the thyratron at the instant the oscillation reaches maximum, the waveform of figure 2-5,B, would result. To discharge on the first voltage peak as shown, the trigger PRF must be twice the resonant frequency of the PFN-charging choke combination.

Recall that the PFN was referred to as a delay line. It is the delay characteristic of the PFN that determines the width of the output pulse. At the instant the thryratron fires, the PFN voltage drops to one half. It remains at this level, discharging through the thyratron, until the wavefront travels to the end of the delay line and returns. At that instant, the last energy has been discharged, and the voltage drops to zero. The result of this action is a "step" on the waveform of a duration equal to the pulse width.

Exercises (412):

1. Draw the untriggered PFN-charging waveform as it would occur in a radar normally operating at a PRT of 909 μsec. Indicate high-voltage level, peak-charging voltage, and timing.

2. Draw the PFN waveform of a radar operating at 1100 pulses per second, 0.7-μsec pulse width, and 10 kV from the HVPS. Indicate voltage levels and the ratio of trigger and charging frequencies.

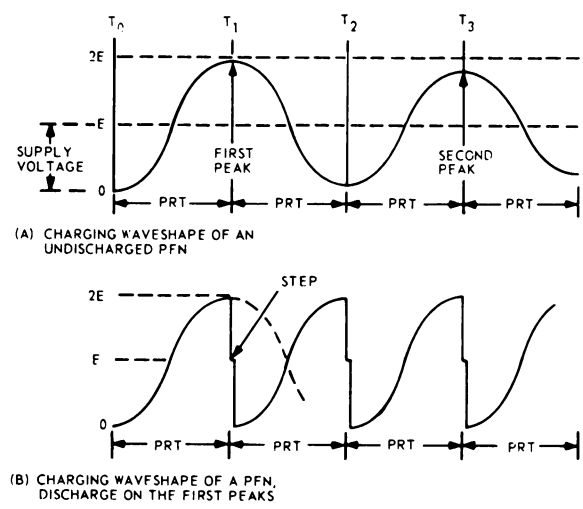

Figure 2-5. PFN waveforms.

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Now that you have completed the sections dealing with the thyratron and the PFN, the time has come when these can be tied together into a modulator circuit. Again refer to figure 2-4.

413. Using a referenced schematic, explain the operation of specific circuit components.

Modulator circuits. Z1, the PFN, charges through L1 toward the HVPS in the manner previously explained. Note that the charging current passes through V3 in series with L1. It is referred to as a holdoff diode or charging diode. This diode allows the PFN voltage to reach twice the supply voltage as in figure 2-5,A, but prevents current flow in the reverse direction. Consequently, Z1 will retain maximum charge until the thyratron is triggered.

When the thyratron is ionized by an input trigger, the PFN discharges to ground through pulse transformer T1, then through the thyratron to the other side of the PFN. If the load impedance, the magnetron, were perfectly matched to the output impedance of the PFN, a rectangular pulse would be formed, and all energy transferred. However, in practice, the modulator pulse is not purely rectangular. In fact, certain deliberate distortions are introduced in order to compensate for peculiarities of the magnetron. To get a rectangular RF output from the transmitter, the actual modulator pulse must closely resemble the one shown in figure 2-6. Its rise time to 85 percent of the peak value is slow enough so that the magnetron can start oscillating in the correct mode. If the rate of rise is excessive, the magnetron may oscillate in an unwanted mode or it may arc and fail to oscillate at all. The correct rise time is produced by L3 in the plate circuit of the thyraton. It is called, logically enough, a sloping coil. Its reluctance to current flow when discharging the PFN is responsible for the sloping action.

A magnetron is not a linear impedance, so matching the PFN to the load is difficult. Before the magnetron breaks into oscillation, it is a very high impedance. Thus, at the beginning of PFN discharge, the magnetron acts like an open circuit and reflects power in phase. This reflection adds to the applied voltage, causing a large spike to be produced, which may reach sufficient amplitude to cause arcing across the pulse transformer. The troublesome spike is prevented from developing by a despiking network consisting of R10 and C1 (fig. 2-4). A normal value for R10 is 50 ohms, so during the rise time of the pulse it presents a matched load to the PFN. By the time that C1 has charged, the magnetron should be oscillating normally.

The remaining rise time above the 85-percent level is as short as possible. The voltage should then remain constant for the duration of the pulse. At its conclusion, the voltage should drop rapidly to stop the magnetron as quickly as possible. After this time, the voltage can be reduced at any convenient rate, but must be slow enough to prevent excessive ringing in the pulse transformer. The oscillations after the pulse in figure 2-6 are about normal.

If the load impedance were lower than that of the PFN, some of the energy would be reflected back in opposite phase and would produce a charge of reversed polarity in the PFN. This reverse voltage would add to the supply voltage during the succeeding charge cycle. The resulting PFN charge would then be about twice the sum of the two voltages. This condition commonly occurs when the magnetron arcs. Should the condition persist, each successive PFN charge would be larger in amplitude than the one before it. Eventually, the charge would reach the breakdown voltage of some component, and the modulator would fail. Such potential for failure is prevented by reverse current diode V2. It conducts whenever a reversed voltage is applied to the PFN, and drains off the potentially troublesome charge.

Exercises (413):
Refer to figure 2-4.

1. What is the function of V2?

2. What is the function of V3?

3. How does the size of L3 affect the modulator output?

4. How would the pulse be affected if R10 opened?

414. State the function of selected items shown on a block diagram of a hard-tube modulator circuit.

Hard-Tube Modulator. The hard-tube modulator used in autotrack systems is divided into a driver unit

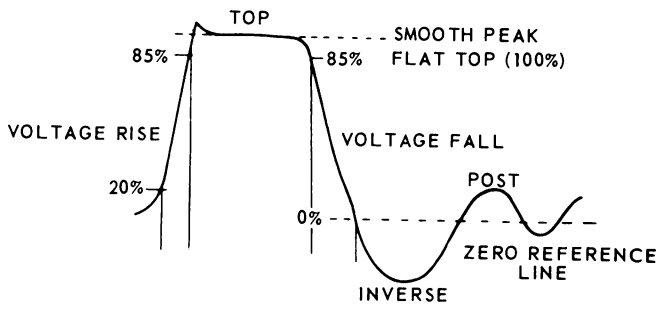

Figure 2-6. A modulator pulse.

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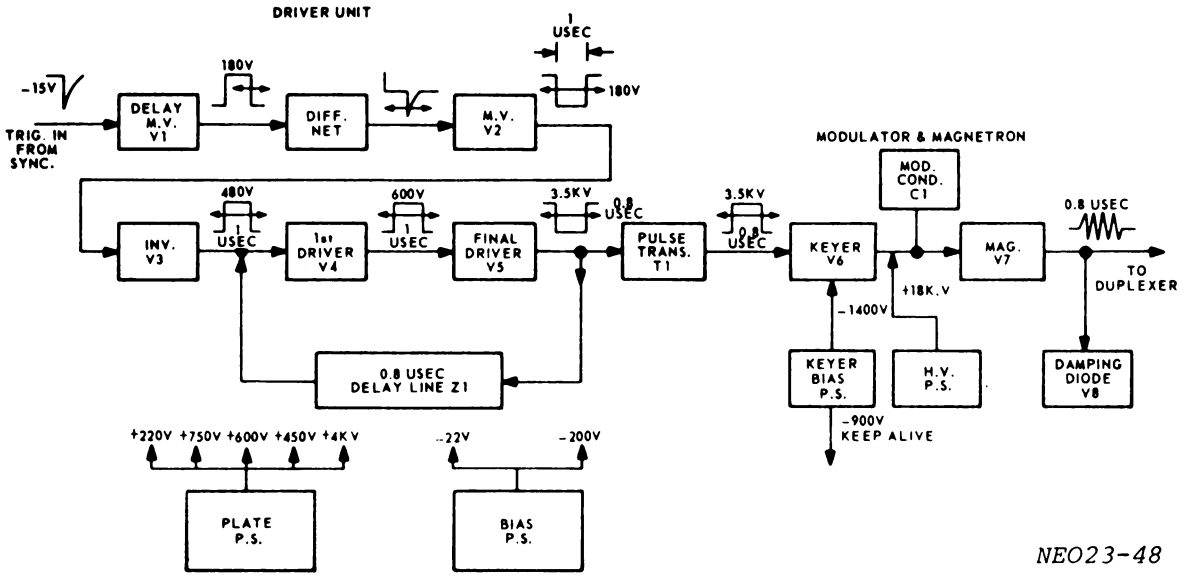

Figure 2-7. Typical hard-tube modulator.

and a modulator. The driver shapes the width of the pulse to 0.8 μsec by use of a delay line and amplifies it to 3500 volts. The modulator stores the necessary power to excite the magnetron and applies this power to the magnetron when the 0.8-μsec pulse from the driver is applied.

Figure 2-7 shows a block diagram of a typical hard-tube modulator. V1 is a start-stop delay multivibrator; the A section is normally conducting while the B section is held cut off by the -22-volt bias. The negative synchronizer trigger causes the A section to cut off, causing a positive pulse to be developed at its plate. The pulse width is variable and can be adjusted to determine when V2 will provide an output. This is necessary in order to delay the firing of the magnetron to compensate for trigger delays in other circuits which must coincide with the firing of the transmitter.

The positive pulse output of V1 is differentiated and applied to V2, also a start-stop multivibrator. The A section of V2 is normally conducting while the B section is held cut off by a -22-volt bias. The output of V2 is a negative pulse, 1 μsec wide, with an approximate amplitude of 180 volts.

The output of V2 is amplified and inverted by V3. The output of V3, a ×480-volt-μsec pulse, is applied to the control grid of the first driver stage.

Stages V4, V5, T1, and Z1 are used to meet the 0.8-μsec pulse width requirement of the transmitter and to further increase the power of the trigger pulse.

The driver stages are designed to handle large amounts of current. In a typical circuit, the driver tubes are dual tetrodes with both sections of the tube connected in parallel. The first driver usually consists of one tube, which is the equivalent of two single tubes in parallel. The final driver, because of the large increase in power, usually consists of two tubes or four single tubes connected in parallel. Both the first driver and the final driver are normally cut off because of the -200-volt bias.

As soon as the output of V3 is applied to the first driver, the stage conducts and produces a -600-volt pulse at its plate. This negative pulse is transformer-coupled to the final driver so that a positive pulse is felt at its grid. This positive pulse overcomes the -200-volt bias, the tube conducts, and a negative pulse -3.5 kV in amplitude and 0.8 μsec wide (as a result of the action of Z1) is developed at its plate. This negative pulse is applied to both the pulse transformer and the delay line.

Z1 is a delay line designed so that its output occurs 0.8 μsec after it receives an input. As you notice, Z1 is a feedback line to the first driver stage. The negative pulse output of the final driver appears at the grid of the first driver 0.8 μsec after the 1-μsec input from the inverter. Since the pulse from the delay line is -3.5 kV, compared to the +480-volt pulse input from the inverter, the first driver is driven into cutoff. The input to the first driver is therefore limited to 0.8 μsec, and all pulses occurring from this point on will be 0.8 μsec wide.

The keyer stage V6 acts as a switch and must handle an extremely heavy current. In a typical circuit, the keyer tube is a triode. Because of the extremely heavy current the keyer stage is required to handle, three keyer tubes are usualy connected in parallel. Each keyer tube is normally cut off by the -1400-volt bias. During the keyer tube cutoff time, C1 is charged to the applied +18 kV which is in series with magnetron V7 and ground. The keyer stage is connected in parallel with C1 and V7. As soon as the +3.5-kV pulse from the pulse transformer is applied to the grid of the keyer tube, the -1400-volt bias is overcome and the stage conducts. C1 is now able to discharge through the

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magnetron and the keyer tube during the application of the 0.8-μsec pulse.

The discharge of C1 causes V7 to develop an RF output at a frequency determined by its cavity. The amount of high voltage applied to the modulator capacitor, and therefore the amount of voltage to be discharged through the magnetron and keyer tubes, determines the pulse power output. These high-power RF pulses from the magnetron are fed to the duplexer in the RF system.

A damping diode is shown at the magnetron output. This diode (usually more than one is used) insures that any oscillations occurring in the magnetron cavity, after the termination of the trigger pulse, are shorted to ground. In this way, the width of the RF pulse output is limited to that of the pulse applied to the keyer tubes.

In this modulator, the power supply voltages determine the various pulse power levels. Using the pulse widths and amplitudes shown in figure 2-7, for example, it is impossible to develop a pulse wider than 0.8 μsec or with an amplitude of more than 18 kV. By changing the pulse width input to the driver stages and increasing the delay introduced by Z1, a wider pulse width output could have been obtained.

Although a number of different devices have been used to generate RF pulses, the one commonly used in autotrack radar systems is the magnetron. It is a tube that is both a power oscillator and an output tube. The high-voltage pulse produced by the modulator is transformer coupled to the cathode of this tube. The magnetron then directly generates the RF output pulse at the transmitted frequency.

Exercises (414):

Refer to figure 2-7.

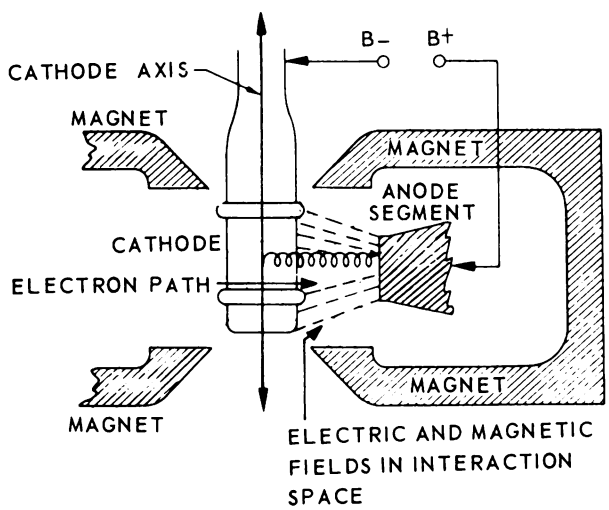
1. What is the function of the driver unit?
2. What determines the pulse levels in a hard-tube modulator?
3. Why are V1 and the differentiating network employed?
4. What is the function of the keyer, V6?

415. State the operational characteristics of a magnetron, and state what factor determines its center frequency.

CAUTION: Operation of the magnetron generates dangerous RF hazards. Care should be exercised to avoid exposure to these radiations. If overexposure is suspected, medical attention should be sought.

Magnetron. A pulsed magnetron is a diode inserted into a nearly constant magnetic field. Its cathode is usually an indirectly heated structure coated with a thorium emitter. Its anode is a solid block of metal into which a number of identical cavities have been machined. These structures are shown in two perspectives in figure 2-8. The cavities can resonate at a frequency determined by their reactive (inductive and capacitive) properties. The magnet is positioned so that its field is perpendicular to the path of an electron moving between cathode and anode.

By a process called *strapping,* the resonant cavities of the anode block are connected together so that a definite electrical phase relationship is established among them.



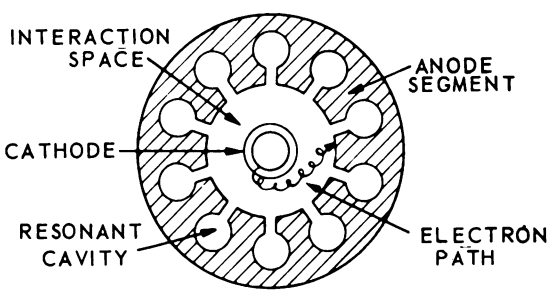


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Figure 2-8. Magnetron structure.

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The relationship among the electrical field, magnetic field, and the phasing of the resonant cavities causes electrons to be bunched. Polarity changes at the cavities cause the bunched electrons to rotate within the interaction space like spokes of a wheel. As these "spokes" pass the cavities, individual electrons give up their energy to the RF fields. This begins and then sustains oscillations. One of the cavities contains a device, usually an inductive loop, that transfers RF energy from the cavity into the transmission line.

Two types of electron emission are useful in the magnetron. The first, thermionic emission, is produced through the heating of the cathode by a tungsten filament. The second is referred to as secondary emission and is caused by nonuseful electrons that are returned to the cathode by the magnetic field. As each of these strikes the cathode's surface, it causes several more electrons to be emitted and results in additional heating of the cathode. From this, we can extract two generalized facts. First, cathode temperature is critical for proper magnetron operation. Second, filament voltage must be reduced during operation to compensate for the additional heating from secondary emission. A correctly adjusted filament control circuit permits application of high levels of anode current without causing overheating of the magnetron.

All of the magnetrons currently used in autotrack radars can be tuned to a specific frequency. Tuning is mechanical, with coupling through a shaft and gear train to a capacitive diaphragm over the resonant cavities of the anode block.

The design application of a particular system generally determines the power and frequency characteristics of the magnetron used. Large magnetrons with large cavities and magnets produce high-power levels, but oscillate at lower frequencies. The effect of the frequency selected must be considered, especially as it affects performance characteristics and the sizes of components. Sizes are in proportion to wavelength. Antennas, particularly, become massive as frequency is reduced. Consequently, most systems are designed to operate at the highest frequency that will satisfy performance criteria.

The condition of the magnet is very important to magnetron operation. The magnet is usually made of alnico, an alloy of aluminum, nickel, and cobalt, that can be energized to high levels of flux density. Magnetron efficiency, typically 40 percent, is adversely affected by any reduction of this magnetic flux below the optimum design level that comes from the factory.

A few simple practices can prevent most flux loss. First, magnetrons should always be handled like the delicate devices that they are, with storage and shipment by technical order procedure. Second, use of bronze tools for installation of a magnetron is a must. If you don't have bronze tools, get them.

Exercises (415):

1. What determines the center frequency of a magnetron?
2. What is strapping?
3. How is magnetron temperature stabilized during operation?
4. What is the most important factor in protecting a magnet?

416. State the function of selected items on a circuit diagram of a transmitter, and identify a selected meter reading for a given condition.

Transmitter Components. As a preliminary to a more detailed discussion, we must first identify the parts that make up a more or less standardized magnetron transmitter. The circuit of figure 2-9 contains most of the common elements.

To prevent the magnetron from drawing current before the filament is fully heated, a 5-minute delay circuit is provided. Relay K1 is part of this circuit. For 5 minutes after power is applied to the radar system, K1 is energized and its contacts short resistor R2, removing it from the primary circuit of the filament transformer T4. This increases the current through the primary of T4 and increases the heater current of the magnetron. At the end of 5 minutes, K1 deenergizes, opening its contact and placing R2 in series with the primary of T4. This reduces the heater current so that the magnetron filament does not overheat as the magnetron begins to draw current.

The -8000-volt, 0.25-μsec modulator pulse is applied to the primary of pulse transformer T3 and is stepped up to -38 kV before it is applied to the cathode of the magnetron. This places a negative voltage at the cathode, starts conduction, and causes the magnetron to oscillate. The magnetron plate current path is from the ground through R23, M1, K2, Z1, winding 3-4 of T3, L1B in parallel with R19, R20, and R21 to the cathode of the magnetron. Relay K2, which is energized when magnetron current flows, places R3 (28 ohms) in series with R2 and the primary of T4. This further reduces the heater current during the time the magnetron is operating.

Resistor R23 functions as a magnetron current monitor. The voltage drop across R23 due to magnetron current is coupled to the TRACK meter located on the power control panel of the radar console. During normal magnetron operation, the TRACK meter and meter M1 show 3.5 mA. Network Z1 is a filter which removes the high-frequency components of the magnetron current and assures a constant value for the metering circuit. Inductors L1A and L1B increase

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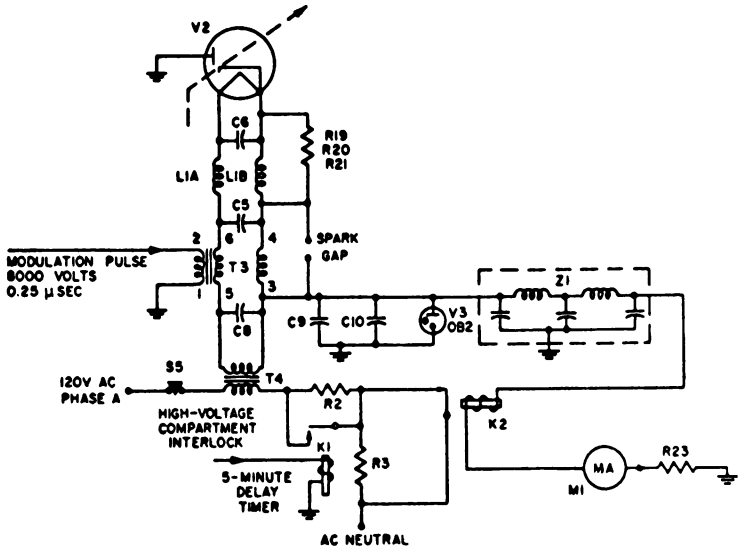

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Figure 2-9. Tracking magnetron group, simplified schematic.

the rise time to the modulator pulse applied to the magnetron to prevent the application of the full voltage before the magnetron oscillates. Resistors R19, R20, and R21 load the inductors and prevent their oscillation with the capacitance of the circuit. Capacitors C5, C6, and C8 insure that there is no high difference of potential between the two secondary bifilar windings of T3.

Should the magnetron leads open, or current not flow through the tube, the modulator pulse would build up a large voltage across the secondaries of T3. To prevent this, a spark gap is placed across one of the secondary windings to discharge the high voltage. Parallel capacitors C9 and C10 bypass the current surges around the metering circuit. Should the current path through the meter circuit open, voltage regulator V3 will ground the static charge built up in the magnetron filament circuit.

The magnetron frequency is varied by changing the effective cross-sectional area of the resonant cavities. This is accomplished by the magnetron tuning drive motor B2 (see fig. 2-10) which turns a worm gear against the calibrated tuning head of the magnetron through a flexible shaft. The head turns a screw that slides a block, containing tuning plugs, in or out of the magnetron, depending on the direction of rotation of the motor. The tuning plugs thus enter or leave the magnetron cavities, reducing or increasing the size of the cavities, and thereby raising or lowering the frequency at which the magnetron resonates. These plugs are carefully aligned so that they enter and leave the cavities without shorting to the side.

Exercises (416):

Refer to figure 2-9.

1. What reading should you expect on M1 when high voltage is off?
2. What is the function of the spark gap?
3. Match each component in column A to its function in column B.

Column A	*Column B*
___a. Pulse transformer T3.	1. Produces RF output pulse.
___b. Magnetron V2.	2. Selects filament voltage.
___c. Capacitors C5, C6, C8.	3. Applies pulse to magnetron.
___d. Relay K1.	4. Maintains secondary windings of pulse transformer at same potential.

417. List in sequence the devices normally used in an RF transmission system.

RF System. The RF system is often referred to as RF plumbing. The analogy is appropriate, for just as pipes route fluids, the parts of the RF system route the transmitted and the received RF to their destinations. If thought of in such terms, the system is not mysterious. It is made up of some basic devices which can be described on a practical level without resorting to the complexities of mathematics.

We shall begin our discussion on RF transmission systems by analyzing a block diagram, paying particular attention to the RF paths for transmitting and receiving.

Figure 2-11 is a block diagram of a typical RF transmission system from a surveillance radar. It shows the principal routing paths for transmitted and received energy. The RF pulse is loop-coupled from the magnetron through an impedance-matching transition device (usually a doorknob coupler) into the waveguide.

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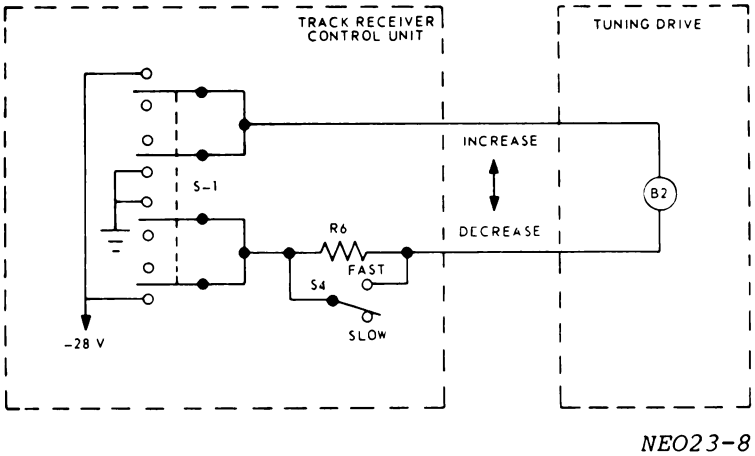

Figure 2-10. Magnetron tuning circuit.

The duplexer routes transmitted energy toward the antenna and switches received energy into the receiver.

Beyond the duplexer, energy flows in both directions. The directional coupler samples the RF at forward and reflected jacks for test purposes. The rotary joint transfers energy from a fixed to a rotating waveguide section. The transition is usually through a coaxial section. The antenna proper consists of a radiating horn (or dipoles) and a reflecting, beam-forming screen.

Exercise (417):

1. Beginning with the magnetron as number 1, number the following components in the sequence of normal occurrence in an RF transmitting system.

___ a. Directional coupler.

___ b. Rotary joint.

___ c. Magnetron.

___ d. Duplexer.

___ e. Doorknob coupler.

___ f. Antenna horn.

___ g. Reflector.

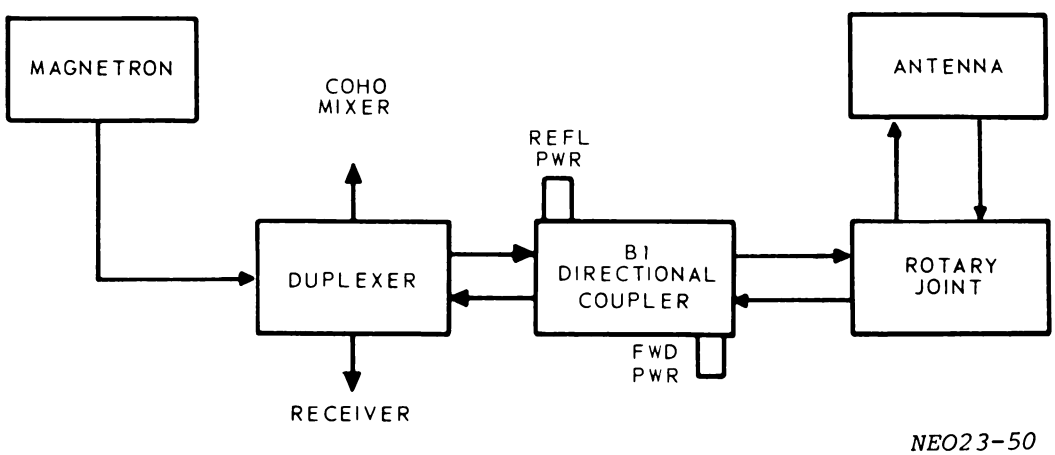

Figure 2-11. A typical RF system.

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418. State the function of a duplexer and its transmit-receive (TR) switch tube.

Duplexers. At this point, it should come as no surprise to discover that a duplexer assembly is an RF switch that allows the use of a single antenna for both transmitting and receiving. Its functional operation can be summarized by considering its basic requirements.

a. It must connect the transmitter to the antenna during the transmission period.

b. It must prevent transmitted RF from entering the receiver (as little as 2 volts can damage the signal mixer diodes).

c. After transmission, the duplexer must quickly disconnect the transmitter and connect the receiver to the antenna. The time necessary to do this, called TR recovery time, must be very short if targets close to the radar are to be seen.

d. The duplexer must not absorb much power nor produce a significant amount of noise.

TR tube. The actual switch in most duplexers is a TR (transmit-receive) tube similar to that in figure 2-12. It is a waveguide section filled with an ionizing gas sealed at both ends by glass windows. Most windows contain several sections separated by spark gaps. These are tuned to resonate at different frequencies to broaden the bandwidth. Resonance increases the difference of potential across the gap, causing rapid ionization of the gas within the gap when the transmitter fires. To hasten the ionization and to reduce the amount of power needed to cause ionization, one of the spark gaps is connected to a keep-alive voltage that is very close to the breakdown potential. This insures quick firing. With keep-alive voltage applied, the TR can fire at power levels around 100 or 200 milliwatts.

Exercises (418):

1. How does a duplexer react to an RF pulse from the transmitter?

2. What function does a duplexer form between transmitter pulses?

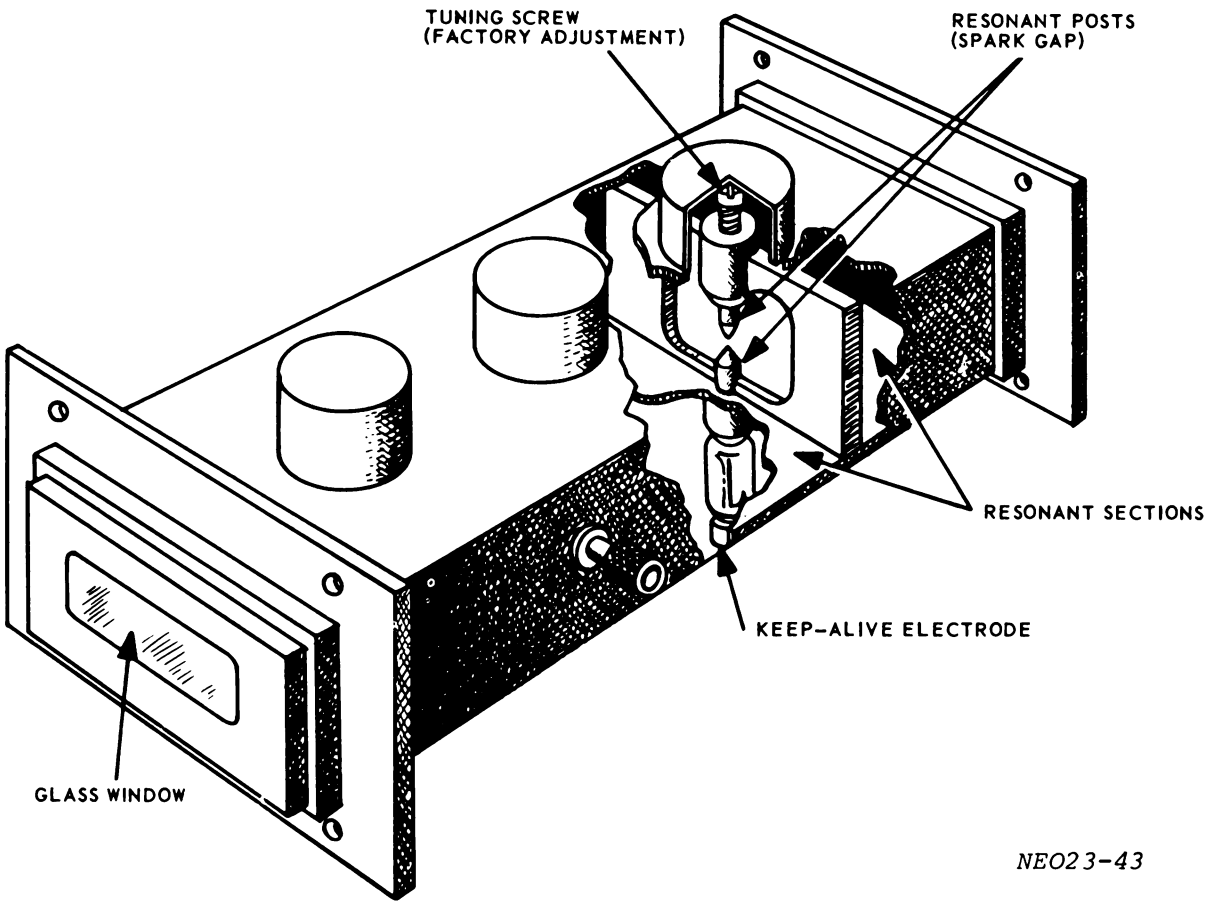

Figure 2-12. Typical TR tube.

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3. Why does a TR ionize when comparatively low-power levels are applied to it?

419. Identify two types of duplexers by a brief description of their operation.

Branched duplexer. The branched duplexer is common to most early radar systems, including some like the MPS-9 that are still in service. In its simplest state, it consists of waveguide sections, a TR tube, and one or more ATR (antitransmit-receive) tubes. Figure 2-13 is a line drawing that represents a branched duplexer in its transmitting and receiving conditions.

The ATR tube is a quarter-wave section of waveguide filled with gas and separated from the main waveguide by a sealed glass window. When the transmitter fires, the gas in the ATR ionizes across the glass window's inner surface. This short circuit across the port causes RF to "see" a continuous waveguide wall.

When the transmitter pulse is applied to the TR, its spark gaps break down, quickly ionizing the gas within the tube. The short across its glass wall acts the same as in the ATR; the RF is routed past it toward the antenna.

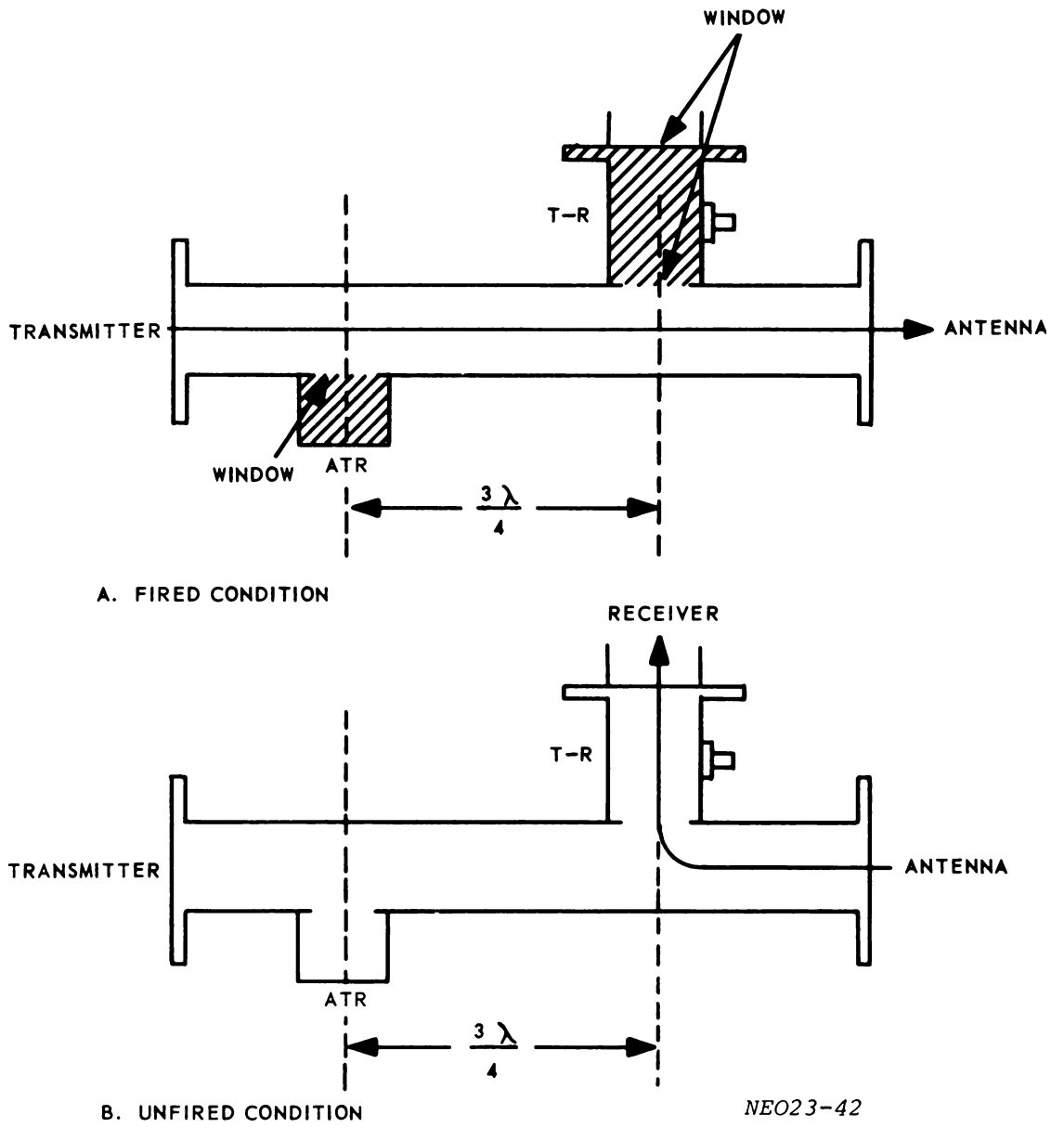

Figure 2-13. Branched duplexer.

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Although the TR prevents most of the transmitter pulse from reaching the receiver, a small leakage spike does get through and appears on the radar indicator as the "main bang" at the start of the sweep. When the TR is performing it function, this spike is normally too small to damage the receiver circuits; but, as the tube ages, the amplitude of the spike can reach a level that is damaging. Then, of course, the TR tube must be replaced.

When the transmitter pulse ends, the ATR and TR tubes deionize. This does not happen instantly. The recovery time is a measurable quantity; if it is excessive, the TR must be replaced.

The echo signals have little energy, so all the energy available must be passed through the TR. The ATR tube insures this by preventing the return of any energy to the transmitter arm of the RF system. When deionized, it acts as a quarter-wave shorting stub and reflects a short circuit across the waveguide at the TR, diverting all the received echo energy into the receiver arm. Although this type of duplexer is simple and compact, it is limited in power-handling capabilities. It is also frequency-sensitive because of its dependence upon spacing between TR and ATR. More advanced circuits have surmounted these problems and have, at the same time, provided greater receiver isolation.

Ferrite circulatory duplexer. The ferrite circulator duplexer shown in figure 2-14 consists of a folded hybrid magic tee, two 45° nonreciprocal phase shifters and a short-slot hybrid. It is a basic, balanced duplexer using the characteristics of hybrids and the application of the nonreciprocal properties of ferrite devices. The operation of this duplexer can be described more easily by first discussing the operation of each component.

The folded hybrid tee, the first section of the duplexer, is a reciprocal isolating microwave network (see fig. 2-15). Energy entering the transmitter port or H-arm divides equally in phase. Energy entering the E-arm also divides equally and leaves via the two side arms; however, there is a 180° phase difference. Conversely, energy entering the hybrid tee from the side arms in phase combines and leaves at the H-arm. If the energy entering the side arms is 180° out of phase (receive condition), the energy will add out the E-arm to the receiver. In each case, the H-arm (transmitter) and the E-arm (receiver) are isolated from each other.

The phase-shifter sections are two special pieces of waveguide joined at the sidewall, with a ferrite slab attached to the top wall of each section. Magnets placed around the phase shifters apply magnetic fields to the waveguide and ferrite slabs. The direction of the magnetic field in one phase shifter is in the opposite direction from the field in the other. In this application of ferrites, the phase shifter delays in phase (45°) the flow of energy in one direction and advances in phase (45°) the flow of energy in the other direction. Since the magnetic field in each phase shifter is in the opposite direction, energy flowing in the same direction through each will be advanced 45° in one phase shifter and delayed 45° in the other. Thus, the phase difference between energy passing through the two phase shifters is changed by 90°.

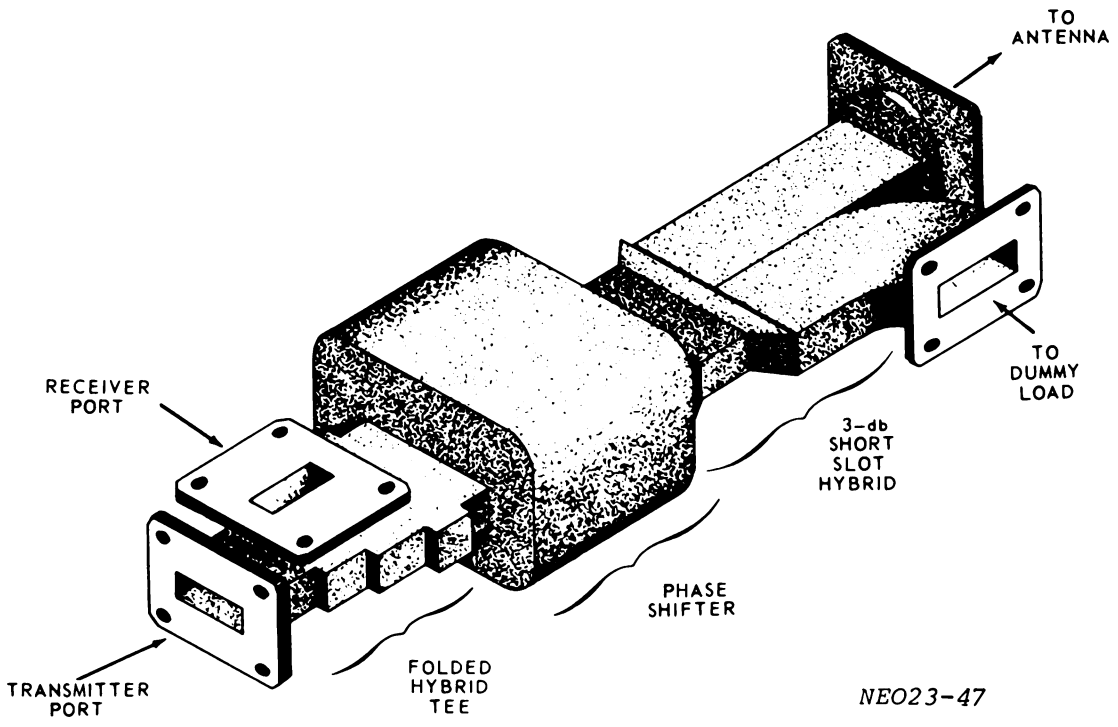

Figure 2-14. Circulator duplexer.

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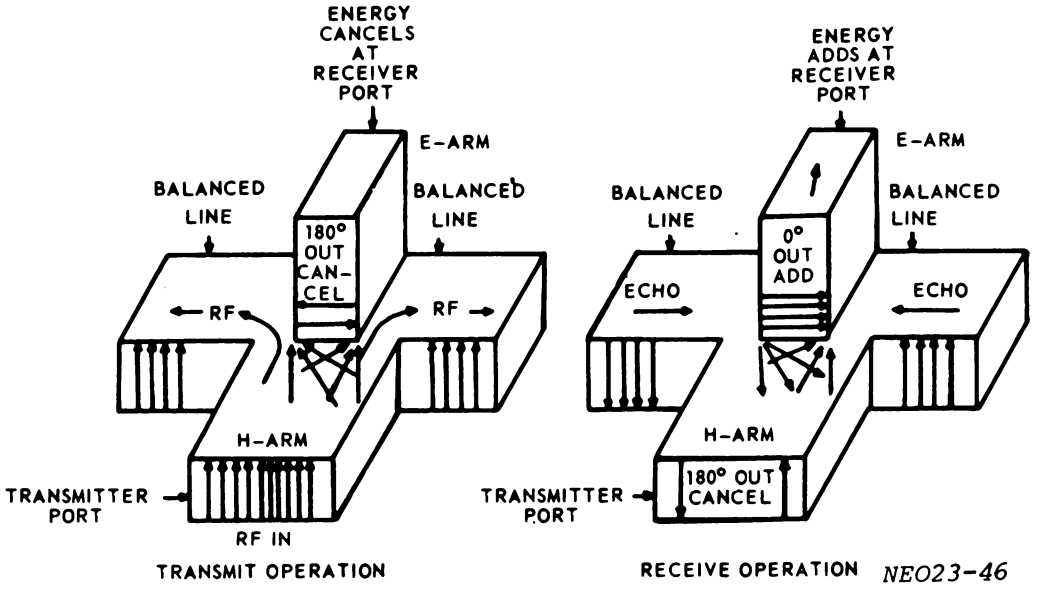

Figure 2-15. Magic tee.

The 3-dB short-slot hybrid is the third section of the ferrite circulator. In appearance, it is two sections of waveguide side by side with a hole in the common sidewall (see fig. 2-16). It is sometimes referred to as a sidewall coupler.

The operational characteristics of the short-slot hybrid are shown in figure 2-17. Energy entering at arm 1 travels to the opening between the waveguide sections. If all the arms are properly terminated, the energy, PT, upon reaching the common point between the waveguides, divides equally. Half of the energy travels out arm 3 and the other half out arm 4. The energy traveling the longer distance, that is, through the opening into arm 4, receives a 90° phase lag in respect to the energy at arm 3. This 90° phase shift is the most important characteristic of this hybrid section. As long as there is equal power separation (3 dB) of the signal between arms 3 and 4, arm 2 will be isolated.

The short-slot hybrid is a reciprocal device; that is, if energy enters arms 3 and 4, equal in amplitude and 90° out of phase, the energy will add and travel out of arms 1 and 2. One output arm is terminated in a dummy load, and the other output arm connects through other waveguide sections to the antenna system.

The operational characteristics of the complete circulator duplexer is shown in figure 2-28. During transmit operation, as seen in figure 2-18,A, energy enters the H-arm of the magic tee, splits equally, and leaves via the two side arms in phase. In the ferrite phase shifters, the energy will be delayed 45° in one and advanced 45° in the other. Thus, the phase of the energy in the top will be advanced 90° in relation to the phase of the energy in the bottom. The two signals then enter the short-slot hybrid where the energy is again shifted by 90°. (This operation was previously discussed.) Upon leaving the short-slot hybrid, the phase relationship will be correct for the signals to combine in the antenna arm.

On reception, as seen in figure 2-18,B, energy enters the short-slot hybrid and is divided equally. The phase shifts introduced by the ferrite phase shifters are now reversed because the energy is flowing in the opposite direction. The phase of the energy in the bottom will be advanced 90° in relation to energy in the top. Now, the energy entering the side arms of the magic tee has a phase relationship of 180°. This is the proper phase relationship if the two signals entering the side arms of the magic tee are to recombine in the E-arm (receiver) with no energy entering the H-arm (transmitter).

A protector TR tube may be inserted in the receiver arm as protection against any mismatches of impedances. As previously described, all the energy entering the H-arm of the magic tee from the transmitter is propagated toward the antenna. Small discontinuities, or mismatches, in the waveguide system from the output of the duplexer to the antenna reflect back to the input arm of the short-slot hybrid. This energy

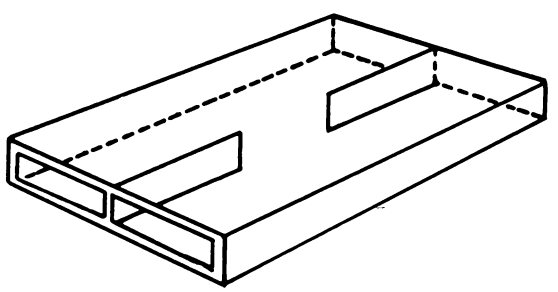

Figure 2-16. Short-slot hybrid.

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will be reflected by the ionized TR tube and will propagate from the E-arm of the magic tee to the dummy load termination of the short-slot hybrid.

Exercises (419):

1. Identify the type of duplexer assembly indicated.
   a. RF phase is shifted by ferrites.

   b. The transmitter arm is short-circuited when receiving _____ .

2. If the transmitted energy into a circulator is instantaneously at +90°, what is the phase at the antenna output port?

3. When can the receiver function?

4. What is the function of the ATR during transmit time?

420. Given a list of selected statements, identify the type of antenna array discussed in each.

In this section, we are going to briefly discuss the most common types of antennas employed with automatic tracking radar systems.

Antenna Arrays. The antenna acts as a transducer between free space and the waveguide. It establishes the required beam pattern and points the beam in the desired direction. The types of antennas that may be used are limited by the purpose, function, and frequency range of the system. The design engineer still has some latitude in his selection.

Most autotrack radars use antenna arrays built around the parabolic reflector. The two types are: (1) dipole feed parabolic and (2) Cassegrain.

Figure 2-19 shows the *dipole feed array*. The dipole element feeds directly into the parabolic reflector which focuses the RF energy into a conical shaped beam and directs it into space. One of the disadvantages of this array is that some of the energy reflected by the parabolic reflector enters the feed (dipole and parasitic reflector) and acts like any other wave traveling in the reverse direction in a transmission line. An impedance mismatch is caused by the standing waves generated along the line.

Figure 2-20 shows a *Cassegrain* antenna. The feed is located at the vertex of the parabolic reflector and a hyperbolic subreflector is located in front of the antenna between the focus and vertex. The size and position of the hyperbolic subreflector are interdependent. The larger the subreflector, the closer it is placed to the parabolic reflector; however, a large subreflector results in aperture blocking. Therefore, the size of the subreflector is a compromise on aperture blockage and distance from the parabolic reflector. It has been said that the overall length of a parabolic antenna array can be reduced by a factor of two when redesigned as a Cassegrain.

An important advantage of the Cassegrain antenna is that the RF plumbing can be placed immediately behind the reflector. This reduces the length of transmission lines required.

Exercise (420):

1. Identify the type of antenna array discussed in each of the following statements. Write your answer in the space provided.
   a. Built around a parabolic reflector.

   b. Makes use of a hyperbolic subreflector.

   c. Feeds directly into the parabolic reflector.

   d. Causes an impedance mismatch in the RF section during transmission.

   e. Has the shortest overall length.

   f. Requires the longest transmission lines.

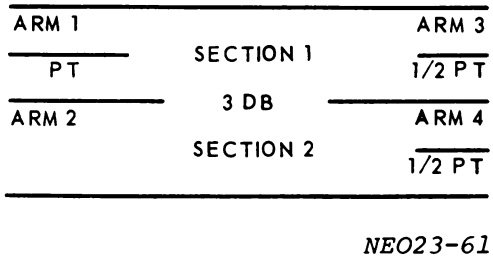

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Figure 2-17. Operation of short-slot hybrid.

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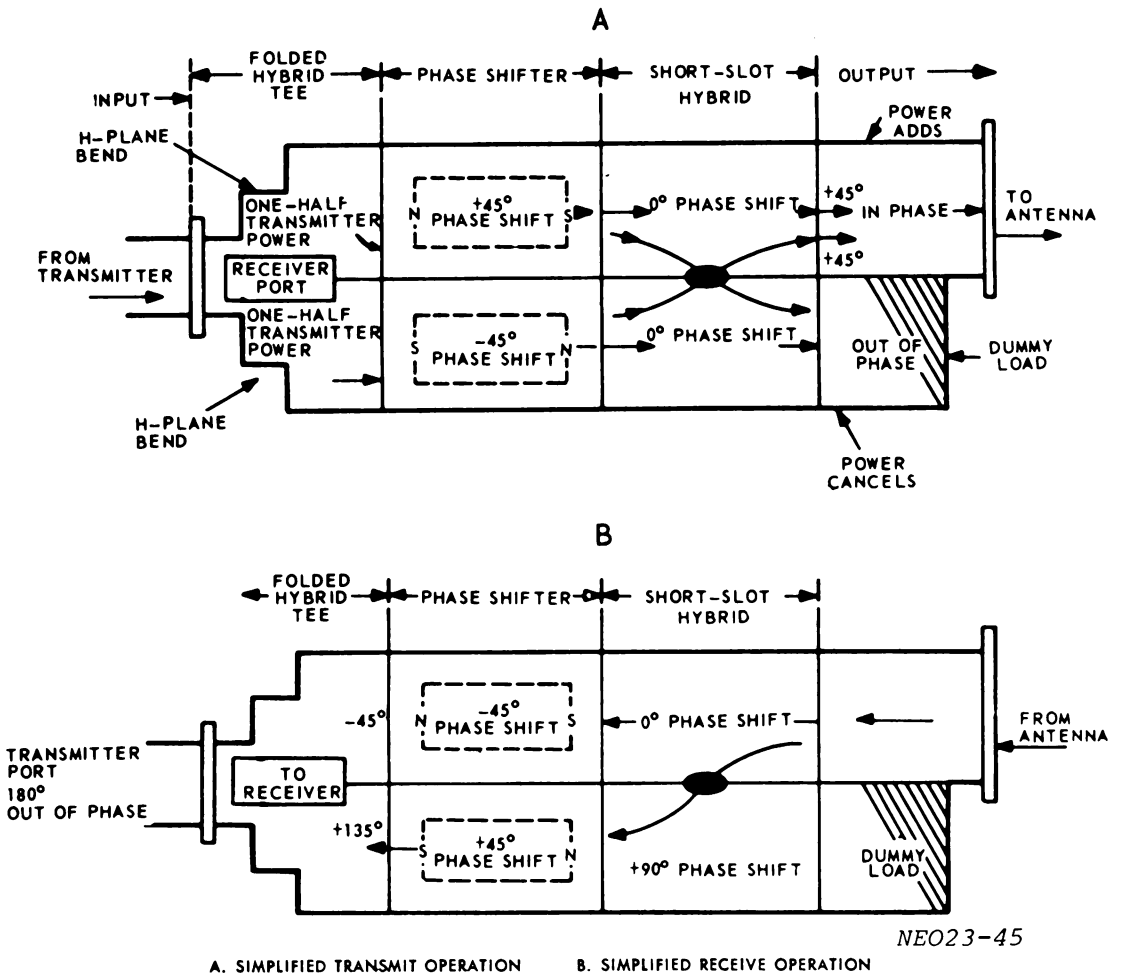

Figure 2-18. Circulator duplexer.

2-3. Transmitter Performance Testing

Few, if any, experienced radar technicians would argue with the statement that maintaining the transmitter system is hard work. The assemblies are heavy and dangerous to work on. They contain voltages that can certainly be lethal to the foolish and unwary. Many of the methods and techniques that are routine for most circuits cannot be used here. You cannot, for instance, check the output of a high-voltage power supply with a VOM. Fortunately, procedures and test equipment are available that can be used to keep your system in top-notch condition. They begin with the day-to-day cleaning, performance testing, and aligning.

421. Describe four general types of tests and five types of alignments important in performance evaluation of a radar transmitter system.

Performance Evaluation. If the many meters, lamps, and test points provided on component front panels are observed routinely, many maintenance problems will already be half-solved when they occur. Both sudden and gradual performance changes will become apparent to the technician who knows what normal indications should be and keeps record of them on a day-to-day basis. The equipment TO is

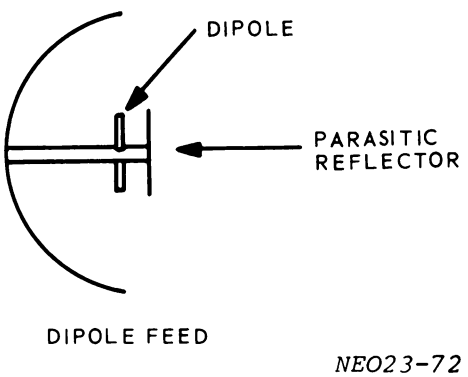

Figure 2-19. Dipole feed array.

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always the best source and final authority for the standard performance figures. These should be committed to memory and also a sequence for checking them. Among these figures should be:

a. Normal readings of panel meters that measure low voltage, high voltage, rectifier current, magnetron anode current, and magnetron filament voltage.

b. Waveforms at panel test points such as those labeled system triggered, driver pulse, modulator pulse, magnetron pulse, and current pulse.

c. The normal state of panel lamps that show the status of switches, relays, interlocks, and fuses.

External test equipment connected to various test points can measure various systems. Most often monitored are transmitter frequency, average power, and magnetron spectrum. Any deviation of these beyond limits or minimums stated in the TO is reason for immediate attention. Here again, to know the correct figure is to recognize the incorrect.

Preventive maintenance routines are done less frequently than performance checks, but are of equal importance to dependable operation. High-voltage circuits act like electrostatic vacuum cleaners—they literally pull the dust out of the air. This dust, when mixed with a bit of insulating oil leakage, can soon set the stage for high-voltage arcing down the sides of insulators. Because of carbon deposits on arc paths, curing such a problem is much more difficult than preventing it by proper cleaning and inspection.

The final category was partially covered in the previous section. Those alignments and a number of others must be done on a routine basis, although a properly operating transmitter should require neither frequent nor detailed realignment. In those cases where alignments are difficult to do or where the frequency of routine realignment increases, the indications and circuit responses may provide the technician with clues to an approaching failure. Among the alignments done routinely are power supply, capsule voltage, overcurrent, magnetron filament, and magnetron frequency adjustments.

Exercises (421):

1. Briefly describe the four types of performance tests explained in the preceding paragraphs.

2. Identify at least five alignments required in a typical radar transmitter system.

422. From a simplified diagram, explain the reaction of selected circuit elements of an echo box to input RF as the cavity is tuned through resonance.

Transmitter frequency must sometimes be measured several times a day. The echo box provides the most convenient method of doing this. Therefore, we will introduce the subject of frequency measurement by taking a quick look at this very useful piece of test equipment.

Echo box and wavemeter circuits. An echo box consists of a cylindrical resonant cavity with a movable plunger inside that can vary the dimensions of the cavity. Such a device is shown simplified in figure 2-21. The plunger is connected through a gear-driven mechanism to a calibrated tuning dial. This dial can be calibrated directly in frequency or in arbitrary units that must be converted to frequency by using a calibration chart.

The cavity of the echo box is an extremely high-Q resonant circuit. Its inner surfaces are polished and silver plated to reduce losses. Input RF is applied to the cavity through a coaxial cable from the bidirectional coupler, a device that samples a very small fraction of total transmitter power. When the cavity is tuned to the frequency of the input, each radar pulse excites the buildup of oscillations within the cavity, as shown in figure 2-22. After the radar pulse ends, resonance continues until the energy within the cavity has been dissipated. This occurs in three ways. Part of the energy is returned through the coaxial cable into the radar waveguide. (We will return to this point when discussing receiver testing.) Another part of the energy—a small part— is simply lost within the cavity. A third portion is transferred into the metering circuit.

This third portion is of greatest interest at the moment, for it is rectified, filtered, and applied to a sensitive microammeter. A variable attenuator can be

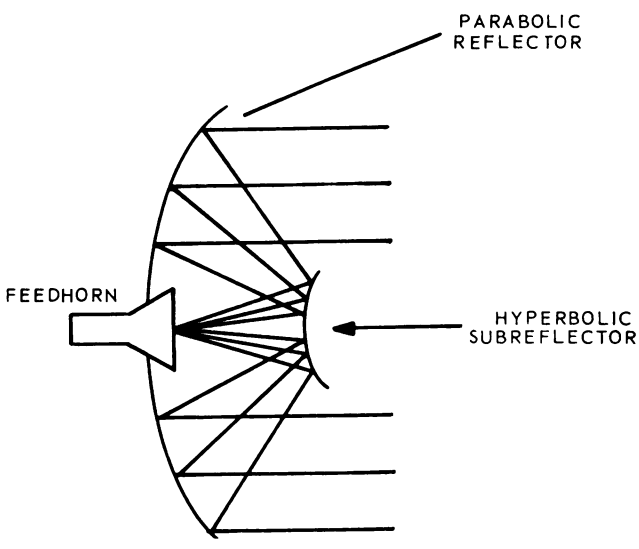

Figure 2-20. Cassegrain.

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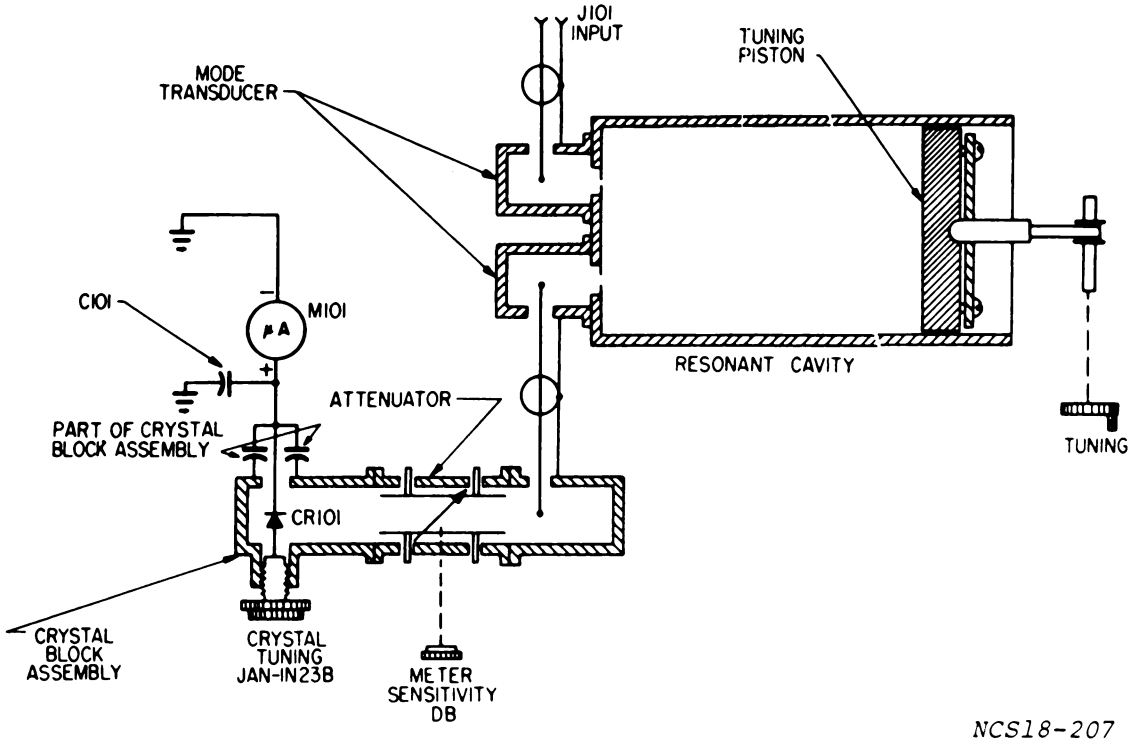

Figure 2-21. Functional schematic of TS-488 ( )/UP.

adjusted to absorb part of the RF as a means to control the maximum meter deflection. For greatest accuracy, it should approach, but not exceed, full-scale deflection. The amount of meter deflection at resonance is in direct proportion to the amount of RF power applied into the echo box. If the echo-box cavity is detuned from resonance, the meter deflection will decrease. These last two statements are the basis by which the echo box can be used to measure both relative power and transmitter frequency.

Exercises (422):

1. What happens to the DC level applied to the microammeter as the echo box is tuned through the transmitter frequency?

2. From one day to the next, under identical test conditions, the maximum meter readings on an echo box drop by 20 percent. What could be a logical explanation?

423. Outline the steps in the procedure for measuring and adjusting transmitter frequency with an echo box or wavemeter.

Measuring and adjusting the frequency. To measure transmitter frequency, connect the echo box to the transmitted power jack on the directional coupler, using the standard coaxial cable supplied with the echo box. After the system has operated long enough to stabilize, tune the echo-box frequency through its range until deflection is noted on the echo-box meter. Tune completely through this point and look for the spot where maximum deflection occurs. As precisely as possible, set the echo box at that point.

On some echo boxes, the frequency can be read directly from the tuning dial, while on others it must be obtained from a calibration chart. An example of the latter is shown in figure 2-23. The edge of the outer dial may contain frequency markings in 1-MHz steps that are good enough for estimation; but for accuracy, the charts must be used. On the dial shown, the outer ring is read first, then the inner ring. The composite reading is 16.23. Referencing this reading to the calibration chart will then give the exact frequency—269.5 MHz, for example.

After measuring the frequency, tuning the magnetron to a different frequency is a simple process. First, reset the echo-box frequency dial to the desired frequency. Then turn the magnetron manual tuning control in the direction of change. (In some systems, the AFC must be turned off when tuning the magnetron.) The echo-box meter reading will peak when the magnetron has reached the correct frequency.

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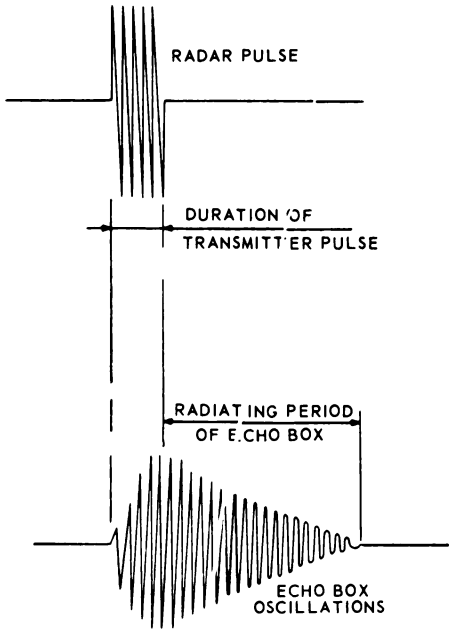

Figure 2-22. Relationship between transmitter pulse and echo-box ringing.

Exercises (423):

1. Outline the three major steps in measuring the frequency of an operating magnetron.

2. What two additional steps must be added to retune a magnetron?

424. Use a conversion chart to compute the decibel equivalent of power in watts and milliwatts and vice versa.

Power Measurements. Power from a pulsed radar transmitter is usually measured at its average value by a thermistor-bridge power meter. Recall from the beginning of Chapter 2 that the average value is the peak power of the magnetron RF pulse multiplied by the duty cycle of the transmitter system.

Decibel power ratio. Although average power is often stated in watts, for the sake of simplicity, power computations are usually accomplished using decibels. Decibels are ratios derived from common logarithms. A ratio is a comparative relationship between two quantities, such as 4 to 1 or 1000 to 1. Common logarithms are exponents of powers of ten. For example, the number 1000 can also be written 10^3. The 3 is the exponent and means that 10 should be multiplied by itself three times. Other examples are 10^5, meaning 100,000, and 2×10^6, meaning 2,000,000.

In common logarithms, the exponent is used by itself. For instance, 10^3 can be written as log 3.0. To express a ratio in such form, we simply attach the term "bel." The ratio 100:1 then becomes 3 bels. The bel is a large unwieldy quantity, so it is divided into 10 smaller increments, each of which is called a decibel. The ratio 1000:1 then becomes 30 decibels, abbreviated as 30 dB.

A pure ratio does not indicate the size of either component. For instance, 1000:1 simply means that one quantity is a thousand times larger than another without specifying either quantity. Therefore, to translate a ratio into measurable terms, it must have a reference or zero point. For radar power measurements, the reference is always a standard of 1 milliwatt = 0 dBm. The letter "m" is added to dB to indicate the reference. All power levels are stated as dBm above or below this 1-milliwatt reference. For example, 30 dBm means 30 dB above 1 milliwatt or 1000 milliwatts.

Decibel quantities greatly simplify power computations because they can be added and subtracted. For instance, 30 dBm + 40 dBm = 70 dBm is identical to 100 mW × 10,000 mW = 10,000,000 mW. Conversion in either direction between dBm and milliwatts is a simple matter if you use a slide rule or a table of logarithms, but even this step is eliminated when a direct conversion chart is used. By way of example, let's convert 50 dBm to watts using the chart in figure 2-24. Locate 50 on the bottom. Read up to the diagonal and then to the left where we discover that 50 dBm is equal to 100 watts (1×10^5 mW). Converting watts to dBm is simply a reversal of this process.

Exercises (424):

Use the conversion chart in figure 2-24 to solve the following problems.

1. How does an increase of any power level by 3 dB affect the power level?

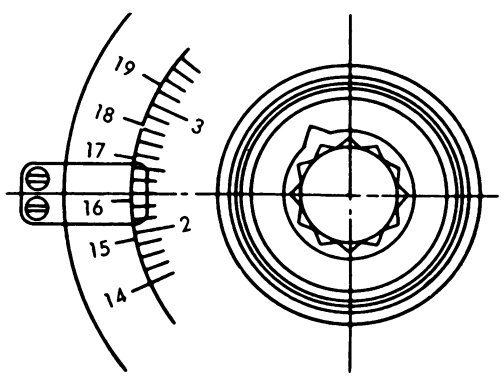

Figure 2-23. Sample frequency dial reading.

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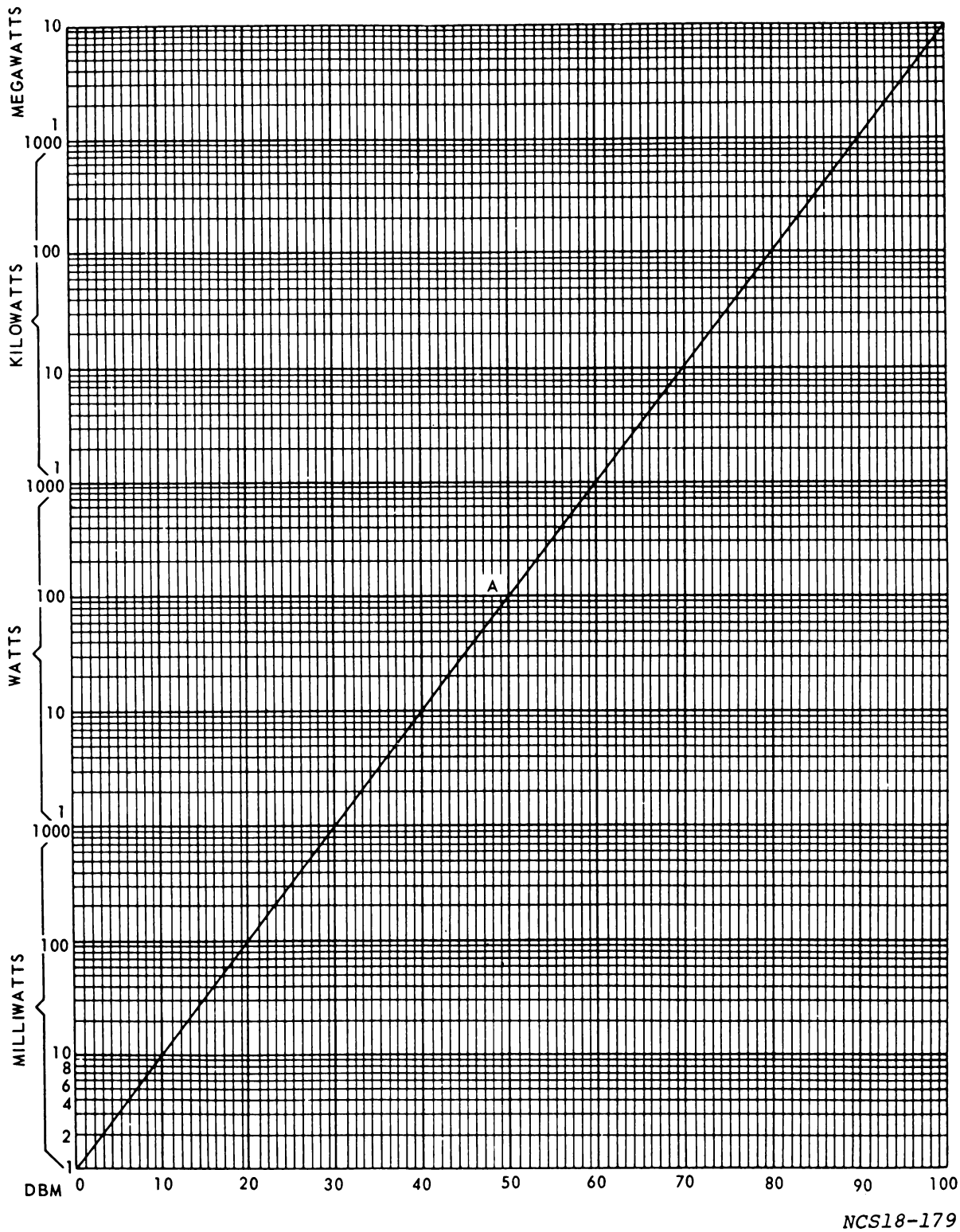

Figure 2-24. Power to dBm conversion chart, 1 milliwatt to 10 megawatt.

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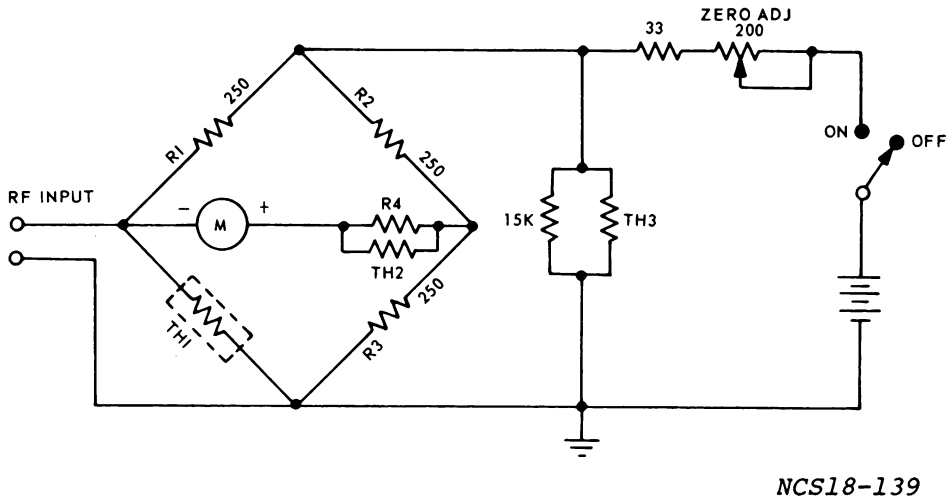

Figure 2-25. Thermistor bridge power meter.

2. The power from a transmitter is passed through three 15-dB attenuators in series and is then measured as 5 dBm. What was the original power level?

3. The power in watts from a transmitter has decreased to one-fourth its normal level. How will this affect the power as measured in dBm?

4. If output power is increased by 10 dBm, how would this affect the measurement as stated in watts?

425. From a simplified diagram of a thermistor bridge power meter, determine the effect of applied DC and RF upon thermistor and meter circuits.

Power meter circuits. Figure 2-25 is a simplified power meter circuit. The active element, the one that reacts to the applied RF, is the thermistor labeled TH1 in the diagram. It is part of a bridge circuit that is adjusted for a balanced state with no RF applied. When the bridge is balanced, no current flows through the meter. The Zero Adjust controls the resistance of the thermistor. It is set for the current level at which the thermistor's temperature causes its resistance to equal the resistance of R3. RF is then applied and is dissipated across the thermistor as additional heat. The heating effect reduces the resistance of the thermistor in proportion to the amount of RF applied. The bridge becomes unbalanced, and current flows through the meter.

Because the amount of meter deflection is in direct proportion to the level of applied RF, the meter can be calibrated for accurate readings. Figure 2-26 shows two commonly used meter scales. The one labeled A is used with a variable attenuator. It is zeroed to the left, RF applied, and the attenuator then adjusted for a midscale reading on the meter. The dB reading is taken from the calibrated attenuator scale. Meter B is also zeroed to the left of the scale, but is used with fixed, calibrated attenuators. The power level at the thermistor is read directly from the meter face in either dBm or milliwatts.

Exercises (425):

1. If the bridge is balanced, what will be the reading on meter B in figure 2-26?

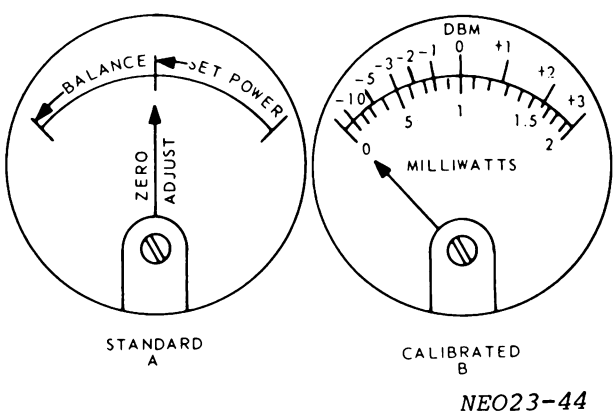

Figure 2-26. Typical power meter scales.

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2. If meter B reads 0 dBm, but no RF is applied, what must be done and how is the thermistor affected?

3. When RF is applied to a bridge, how is the thermistor affected and how does the power meter react?

426. Given a list of components and their attenuation ratios, draw a diagram of test connections and determine the average radar power in watts.

Power determination. When using a thermistor bridge power meter, only a small sample of the transmitter's output power is actually measured. Various types of directional couplers and fixed or variable attenuators are used to reduce this sample down to near a 1-milliwatt level. All of the devices used are calibrated in decibels so that their attenuation ratios can be used to compute the original level.

Now, assume that our power meter is connected as in figure 2-27 through a fixed 16-dB attenuator and a 2-dB calibrated coaxial cable to the direct or incident power jack of the directional coupler mounter on the transmitter waveguide. If the calibration tag on the coupler reads 39 dB, the total attenuation is the sum of all three: 57 dB. The reading from the power meter is algebraically added to the latter figure. For example, a reading of −1 dBm (m for reference) indicates a power level from the transmitter of +56 dBm. Using the chart in figure 2-25, this converts to about 400 watts average power. If this figure is compared with the minimum performance figure given in the equipment TO, it is a simple matter to decide whether power output is adequate.

Exercises (426):

The thermistor bridge reads + 2 dBm during a power check. A 3-dB cable, a 10-dB attenuator, and a 16-dB attenuator were used in connecting it to a 35-dB directional coupler.

1. Diagram the test connections.

2. Compute the power level in dBm.

3. Compute the average power in watts.

427. Explain the relationship between average power and echo-box meter readings.

Echo-box measurements. When an echo box is tuned to the transmitter frequency, the amount of deflection on its meter is in direct proportion to the transmitter power. From day to day, this reading should not change unless power changes. Therefore, the echo-box meter reading can provide a quick means of checking the relative power output from the transmitter. A sudden decrease of meter reading can usually be interpreted as a reduction in transmitter power. It should be pointed out that this test—though useful—cannot be substituted for the power measurement called for in TO performance checks.

Exercises (427):

1. If on successive days the reading on the echo-box meter is the same when tuned to resonance, what does this tell you about the transmitter?

2. If a decrease in echo-box meter reading is noted, what should you do?

428. State the procedure for measuring VSWR with a thermistor bridge power meter and a directional coupler.

VSWR Measurement. Voltage standing-wave ratio (VSWR) can be measured in several ways. The method presented in the following sections is the simplest. It makes use of the basic thermistor bridge power meter. A second method involving performance monitor circuits has been left for a later volume.

VSWR. The VSWR is a ratio between the power transferred from the magnetron to the antenna and which is reflected back toward the magnetron because of impedance mismatch. Reflected energy is, of course, wasted energy that is mostly dissipated as heat.

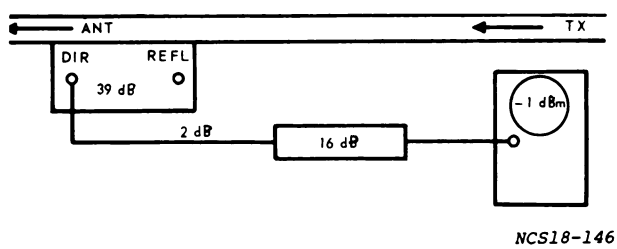

Figure 2-27. Connection for power measurement.

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If the VSWR is excessive, parts of the system can be damaged, which is the reason why VSWR must be routinely measured.

In determining VSWR, the power is first measured in the forward direction as explained in previous paragraphs, and is then measured in the reverse direction. Reverse power is normally so much lower than forward power that most of the attenuation must be removed when measuring it. Refer back to figure 2-27 and notice the reflected jack on the directional coupler. Its attenuation would normally be much lower than the 39-dB figure indicated on the direct jack. In addition to cabling the power meter to the reflected jack, the 16-dB attenuator between coupler and meter would probably be removed or reduced. The computation of reflected power is then done in the same way as for forward power. The meter reading is algebraically added to the total of all attenuations.

Exercise (428):

1. In two short statements, describe how the measurements can be taken to determine VSWR.

429. From specified values of transmitted and reflected power, determine the VSWR from a conversion chart.

Conversion chart. After measuring power in both directions, the figure for reflected power in dBm is subtracted from the figure for forward power. The greater the difference, the better the VSWR. Usually, the minimum permissible figure is stated in the system TO, typically 19 dBm to 21 dBm. If conversion to a ratio is desired, use a chart such as that in figure 2-28. To convert 19 dBm, locate its point along the bottom of the chart. Read upward to the black line and then to the left. The vertical scale indicates that the 19-dBm difference is equal to a VSWR of 1.25.

Exercises (429):

1. When measuring transmitted power, a 2-dB cable and a 16-dB attenuator are connected between the power meter and the direct jack of a bidirectional coupler rated at 35 dB. If the power meter reads +2 dBm, what is the transmitted power in dBm?

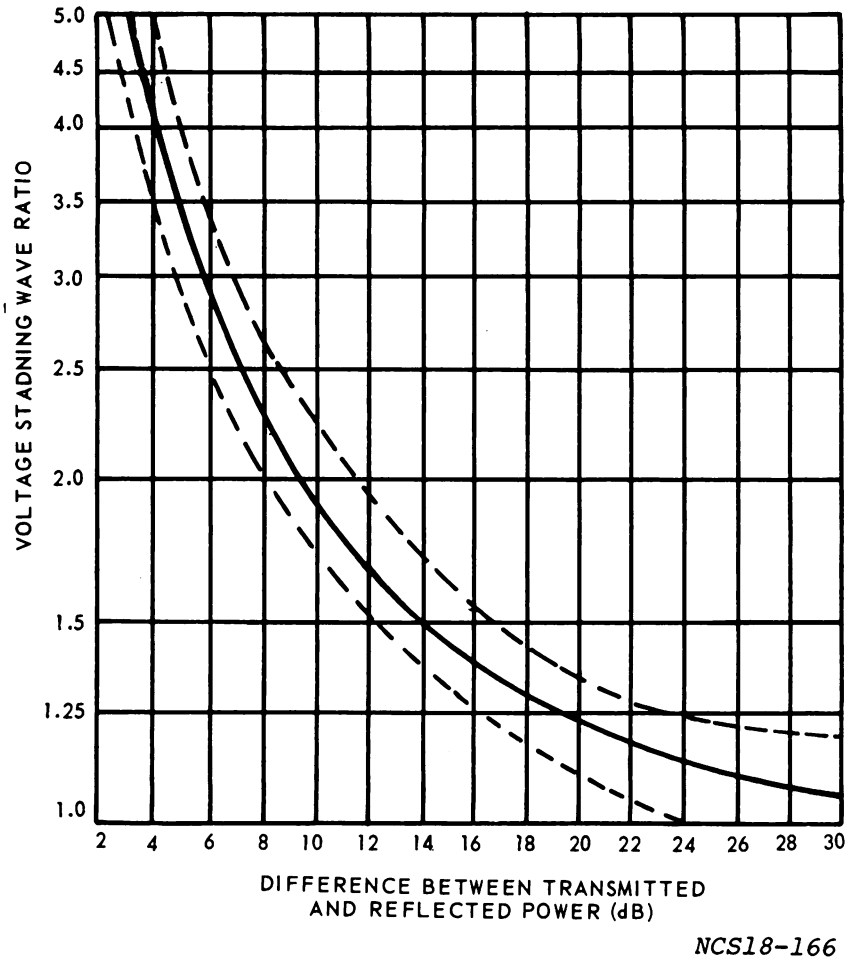

Figure 2-28. VSWR chart.

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2. When measuring reflected power, a 2-dB cable and a 10-dB attenuator are connected between the power meter and the bidirectional coupler's reflected jack rated at 29 dB. If the meter reads –2 dBm, what is the reflected power in dBm?

3. Using the chart in figure 2-28, what is the VSWR that is the equivalent of the measurements in exercises 1 and 2?

4. If the system TO states a VSWR of 1.5 as a minimum performance standard, is the answer to exercise 3 within limits.

430. From the stated characteristics of a radar transmitter, compute the frequencies of major spectrum sidebands and null points.

Spectrum Measurement. The next several pages will acquaint you with one of the more useful aids to troubleshooting the transmitter system—the spectrum analyzer. Also presented is an introduction to the structure of the magnetron spectrum and its interpretation as it affects system operation.

Spectrum display. The power within a radar pulse, no matter what its amplitude as measured by power meter, is not all concentrated at one frequency. Instead, the power is distributed in varying amounts over a range of frequencies called the transmitter spectrum. Figure 2-29 shows the graph of an idealized spectrum from a magnetron. The horizontal dimension shows the frequencies contained within the spectrum increasing from left to right. The vertical dimension represents the relative power contained within the pulse at each of the fequencies.

Not all spectrum resemble that of figure 2-29. For example, the graph of an unmodulated CW signal would be a straight vertical line. Modulation of any sort causes sidebands to be generated. The high-voltage pulse to the magnetron contains many such modulating signals. Because this pulse closely approximates a square wave, it can be considered to be a fundamental frequency plus an infinite number of odd harmonics. All of the frequencies within the pulse contribute to the unique shape of the magnetron spectrum, although, in practice, all above the fifth harmonic are ignored because of their extremely low amplitude.

If the operating conditions of the transmitter are known and a perfectly shaped modulator pulse is assumed, then the spectrum is predictable and approaches the ideal of figure 2-29. For example, a 0.5-microsecond pulse applied to a magnetron adjusted to a 2800-MHz center frequency will produce an output spectrum with the shape and frequency distribution of figure 2-30.

The fundamental frequency of a 0.5-microsecond pulse is 1 MHz, so the third and fifth harmonics are respectively 3 MHz and 5 MHz. These frequencies, when they modulate the 2800-MHz resonant frequency of the magnetron, produce the sum and difference frequencies that are the upper and lower sidebands of figure 2-30. The pulse power at a given frequency is represented by the relative amplitude on the spectrum. There are no even harmonics within the perfect pulse, so these frequencies show up on the spectrum as null points of zero power.

The fundamental and harmonic frequencies increase as pulse width is narrowed. Therefore, the

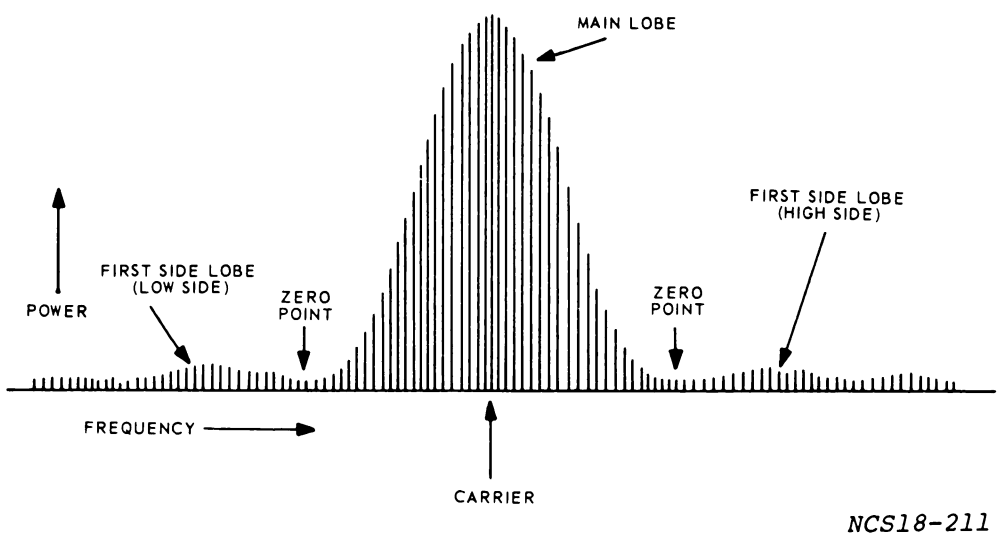

Figure 2-29. Typical spectrum as seen on spectrum analyzer sweep.

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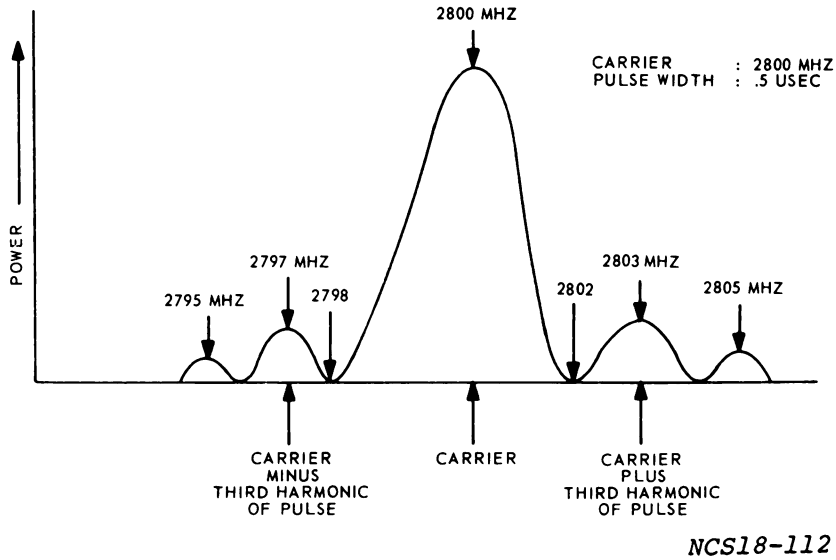

Figure 2-30. Spectrum produced by modulating 2800 MHz with 0.5-microsecond pulse.

bandwidth of the spectrum also increases. In other words, the bandwidth of the spectrum is in inverse proportion to the pulse width.

The width of the pulse is an important consideration, for target resolution is best when narrow, steep-sided pulses are used, as they are in most radar systems. The receiver used with the system must have a flat response to the range of frequencies in the pulse. This point is discussed in much greater detail in later chapters. For the moment, it will be sufficient to note that if receiver response is too narrow, sideband harmonics of the echo pulse are lost and the shape of the video signal to the indicator is degraded.

Exercises (430):

1. If the pulse producing the spectrum in figure 2-30 were changed to 1 microsecond, what would be the frequency of: (a) the main lobe, (b) the first upper null point, and (c) the first upper sideband?

2. If the pulse width in figure 2-30 were reduced to 0.2 microsecond, what would be the bandwidth between the first upper and the first lower sidebands?

431. Analyze the operation of the spectrum analyzer and describe the appearance of a specified transmitter spectrum on the display.

Basic spectrum analyzer. The spectrum analyzer is a combination of a panoramic receiver, an oscilloscope, and a frequency meter. The display on the CRT resembles the spectrum of figure 2-29 and is produced by the circuitry shown simplified in figure 2-31.

The sweep generator produces a sawtooth that is applied to the time base of the CRT. The frequency of this waveform can be varied over a wide range. At maximum, the sweep display will appear to be a fixed, horizontal line; but when slowed, the sweep will begin to flicker.

A negative sawtooth from the sweep generator is also applied through an amplitude control to the repeller plate of the reflex klystron that is used as a local oscillator. Recall that there are two ways to vary the frequency of a klystron. Either the cavity size or the repeller plate voltage can be varied. Both of these methods are used simultaneously in the spectrum analyzer. The cavity size is set by a coarse adjustment that establishes the center frequency of operation. The negative sawtooth to the klystron then causes the frequency to vary across a band of frequencies either side of the center point.

As the sawtooth goes negative, the frequency of the oscillator increases. The duration of the sawtooth establishes the rate at which change occurs. The amplitude of the sawtooth determines the limits of frequency change. In most cases, maximum sweep range will be about 50 MHz. The increase of frequency occurs in conjunction with deflection of the sweep across the CRT. Therefore, it is possible to calibrate the scope trace in frequency with the lowest frequency at the left, increasing toward maximum as the sweep crosses the indicator.

The output from the oscillator is applied to the crystal mixer. The other mixer input is a sample of the transmitter pulse, commonly extracted from the directional coupler. The variable attenuator can

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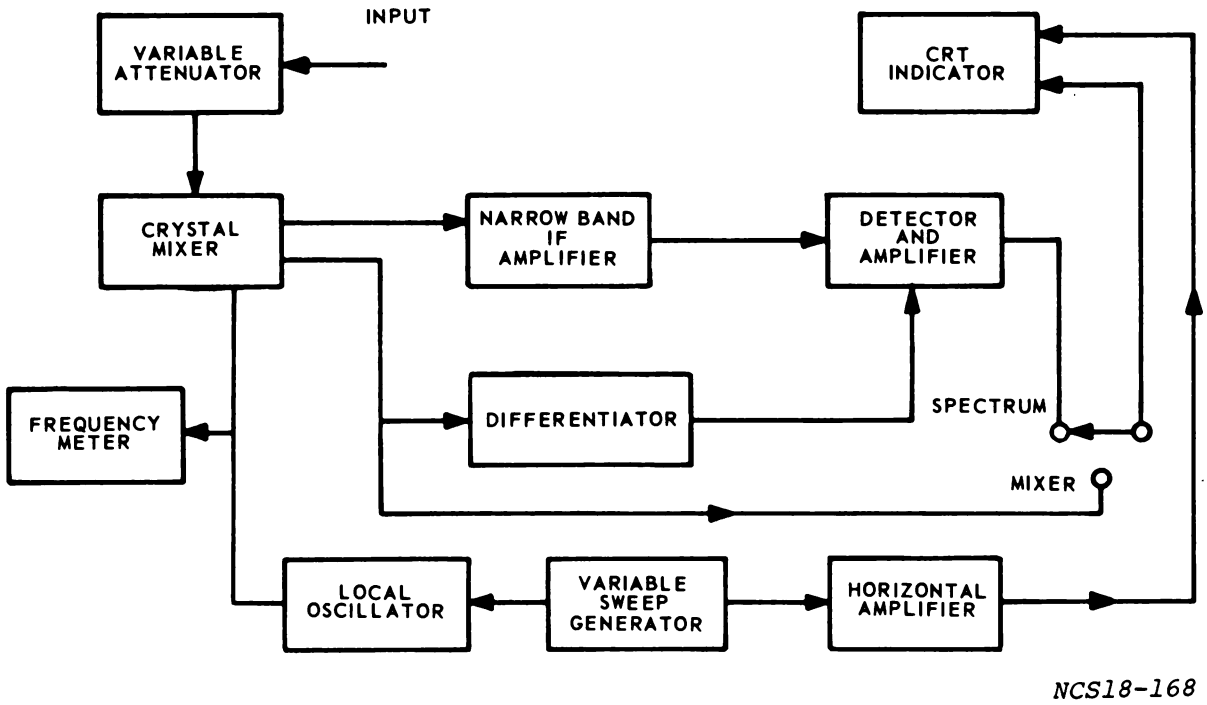

Figure 2-31. Block diagram of typical spectrum analyzer.

further reduce this sample to a level that is optimum for spectrum display.

The difference frequency from the mixer is applied to a narrowband IF amplifier. In one frequently encountered analyzer, the TS-148, the IF is 22.5 MHz with a bandwidth of only 50 kHz. The bandwidth from the magnetron normally covers many MHz; so, obviously, only a very narrow segment of the transmitter's total bandwidth will pass through the IF section.

Because the local oscillator is changing frequency at a slow sawtooth rate, the input frequency that will produce a 22.5-MHz IF must also change at the same rate. The transmitter fires many times during the duration of one sweep and each transmitter pulse contains the full complement of frequencies, but only that 50-kHz segment of frequencies centered on 22.5 MHz will be amplified by the receiver. The selected segment will be displayed on the sweep as a positive pulse with an amplitude that is directly proportional to the power contained in the transmitter pulse at the selected frequency. The composite from a series of these pulses will then be similar to figure 2-29.

It is possible to have two spectra on the display when the oscillator is adjusted to sweep a frequency range that exceeds twice the IF. One spectrum is developed when the oscillator sweeps 22.5 MHz below the transmitter frequency and the second when it sweeps 22.5 MHz above. The two spectra will be identical; either one can be expanded and analyzed.

The frequency meter is a tunable resonant cavity operated by a calibrated frequency dial. When the oscillator sweeps through the resonant frequency of the cavity, part of its energy is absorbed. This produces a dip in the crystal current waveform from the mixer. The waveform is differentiated; the dip in the waveform is displayed as a pip on the CRT time base. Tuning the dial of the frequency meter causes the pip to move along the baseline, where it can be used to read any frequency in the spectrum.

Exercises (431):

1. Describe the appearance of the spectrum display when the local oscillator is centered on the transmitter frequency and adjusted for a maximum spectrum width of 50 MHz.

2. How could you measure the bandwidth of the spectrum in figure 2-29 between the first upper and lower sideband?

432. Given specific transmitter conditions, describe the display seen on a spectrum analyzer.

Interpreting spectrum displays. The idealized spectrum in figure 2-29 is probably not obtainable from a typical radar transmitter. To begin with, it is difficult to generate a truly rectangular high-voltage

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modulator pulse. Furthermore, distortion of the pulse is deliberately induced to improve magnetron performance. Finally, deterioration of almost any component within the RF system can cause changes in the spectrum away from the ideal. Some component failures have very characteristic effects upon the spectrum, so the spectrum can often be a valuable aid to system troubleshooting.

Figure 2-32 shows some of the spectrum variations found in fucntional and defective equipment. In most of these, a simple power check would probably show adequate power output. However, in the middle three, most of the power would be outside the receiver bandpass, so it is useless, wasted power. The troublesome distortion shown here can be caused by an improperly shaped input pulse, a mismatch of impedance in the RF system, or by a defective magnetron.

Probably most common as a cause of poor spectrum is a bad magnetron, but before you assume that simply changing magnetrons is the solution to all problems, consider the fact that many magnetron failures are caused by other problems external to the magnetron. Conditions, particularly in the RF system, that cause magnetron arcing or overheating will

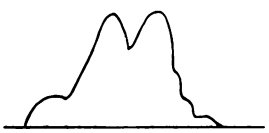
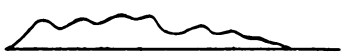
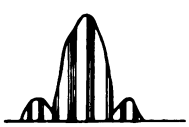
(ANALYZER OR ECHO BOX)	a. Ideal spectrum b. Good radar performance	a. Satisfactory operation
(ANALYZER OR ECHO BOX)	a. High side lobe but acceptable b. Good radar performance	a. Magnetron heater too low b. High load VSWR c. Operating at low magnetron anode current
 (ANALYZER OR ECHO BOX)	a. Split spectrum (double moding) b. Poor radar performance c. Low power output d. AFC not locking	a. Magnetron heater too low b. High load VSWR c. Wrong pulse conditions d. Operating at low magnetron current e. Cathode fatigue (low emission)
 (ANALYZER OR ECHO BOX)	a. Deteriorated spectrum b. Poor radar performance c. Low power output d. AFC not locking	a. Magnetron arcing or misfiring b. High VSWR c. Wrong pulse conditions d. Thyratron trouble
 (ANALYZER)	a. Missing lines b. Poor radar performance c. Low power output d. AFC may or may not lock e. Two separate frequencies several hundred megacycles apart	a. Magnetron arcing or misfiring b. Transmitter trouble c. Transmission line trouble d. Cathode fatigue (low emission) e. Magnetron heater may be too low or too high

Figure 2-32. RF spectrum shapes.

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destroy a perfectly good magnetron. Though the generalities of figure 2-32 are true, it is possible to be somewhat more specific about causes for failure. A high VSWR causes much of the RF to be dissipated as heat and overheated magnetrons fail. Causes are apt to be in conditions such as dirt, moisture, and attendant corrosion in the waveguide; improper seating or connection of parts such as waveguide choke joints and RF bullets; or outright failure of mechanical and electronic assemblies such as waveguide choke joints and RF bullets; or outright failure of mechanical and electronic assemblies such as rotary joints and duplexers.

At the other end are troubles in the modulator and HVPS that affect the output from the magnetron. Figure 2-33 illustrates just one of the processes by which this can occur. Ripple in the high voltage is passed on through variations in the amplitude of PFN charging waveforms. The variation causes a form of frequency modulation in the spectrum that is often referred to as pushing. This particular problem often reveals itself by the fluctuations in the magnetron current pulse.

Exercises (432):

1. If measured power from a magnetron is low and the current pulse is intermittently lost, what would you expect to see on a spectrum analyzer? Why?

2. If the conditions in question 1 occur with regularity as the antenna rotates, where is a likely source of trouble?

433. Outline the procedure for plotting a magnetron spectrum with an echo box.

Spectrum analysis with the echo box. Failure of the AFC to lock-on, frequency jitter, low-power output, etc., are symptoms that may indicate a poor spectrum. Before setting up the spectrum analyzer for a complete check, a rough check can be made with an echo box. The echo box dial is tuned in small increments through the transmitter's frequency range and the meter readings at each point plotted on a graph as shown in figure 2-34. All readings must be taken while rotating the frequency-indicating dial in the same direction. Backlash of the dial mechanism might otherwise contribute to erroneous readings. The approach is usually made from the low-frequency side and then through the spectrum. The plotted points are connected to form the spectrum, but you must be cautious about interpreting the resulting graph. Since the diode in the echo-box meter circuit is nonlinear, the sidebands tend to show up at much greater amplitude than the really are.

Exercise (433):

1. Write three short statements that outline the essential steps in taking a magnetron spectrum with an echo box.

434. Describe the principal difference between probe and panel meters in a TS-15 fluxmeter.

The Fluxmeter. In a preceding section, the point was made that the performance of a magnetron is, to a great extent, determined by the strength of the magnetic field in which it operates. Loss of the

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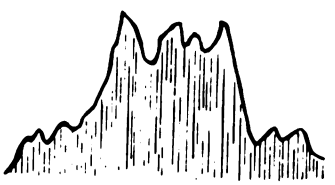
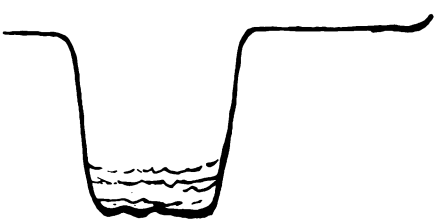


RF SPECTRUM (POOR)



MAGNETRON CURRENT PULSE

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Figure 2-33. Transmitter and spectrum waveforms resulting from HVPS ripple.

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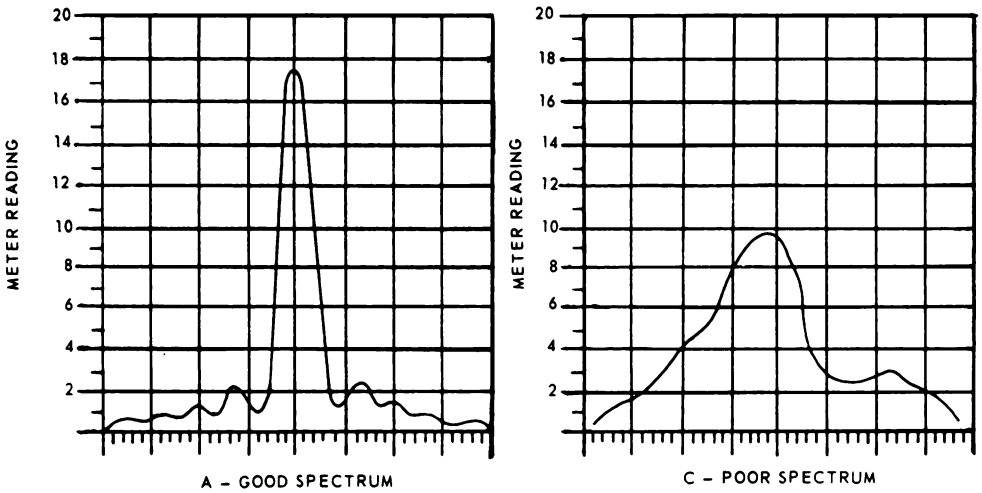

Figure 2-34. Transmitter spectrum.

magnetic strength seriously reduces the efficiency of a magnetron. If greatly reduced, the magnetron may oscillate at the wrong frequency or not at all. To measure the strength of the magnet is a relatively simple procedure if you use a fluxmeter.

Fluxmeters. The typical fluxmeter contains two meters connected in series: a gaussmeter mounted in the test set case as in figure 2-35 and an external probe meter that is placed between the poles of the magnet being evaluated as in figure 2-36. The probe meter differs from the conventional Weston movement in that it has no internal field magnet. The flux to operate and deflect the moving coil is obtained from the magnet under test. Pointer deflection is determined by the coil current and by the flux density in the magnet gap. The amount of current flow required to produce full-scale deflection varies inversely with flux density. With high-flux density, only a small amount of current need flow through the coil to produce full-scale deflection. If flux density is lowered, more current is required to maintain the same amount of meter deflection.

In operation, the current flow through the probe meter is adjusted for a midscale reading. Since the amount of current that will produce midscale deflection is a function of magnet strength, it can be measured by the panel meter of fixed sensitivity and converted to a reading in gauss. (Recall that the gauss is the unit of magnet strength. It is the measure of the number of lines of force per unit area, with one gauss representing one line of force per square centimeter.)

Current flowing through the probe meter also flows through the gaussmeter in series. This meter is on the panel of the test set and is calibrated to read from 1200 to 9600 gauss in three ranges. Its calibration is reversed from actual meter deflection. Meter zero is off the right end of the scale. As magnet flux density decreases, circuit current increases, which is why the meter calibration reads minimum gauss at full scale (the left end of the meter scale).

With a conventional movement, the high-flux readings would be bunched together at the right end of the scale. To avoid this, a retarded zero movement is used. A spring holds the pointer off scale to the right. One milliampere is required to deflect the pointer to the extreme right edge of the scale. The left edge is reached when 2 milliamperes flow through the meter. In other words, the meter reads 1-2 milliamperes rather than the 0-1 milliampere of the conventional meter movement.

Exercises (434):

1. Describe the difference between a probe meter and a standard Weston movement as used in a TS-15 fluxmeter.

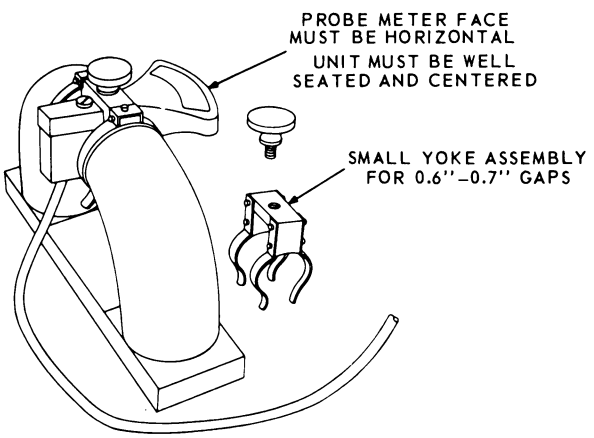

Figure 2-35. Probe meter and yoke adapter.

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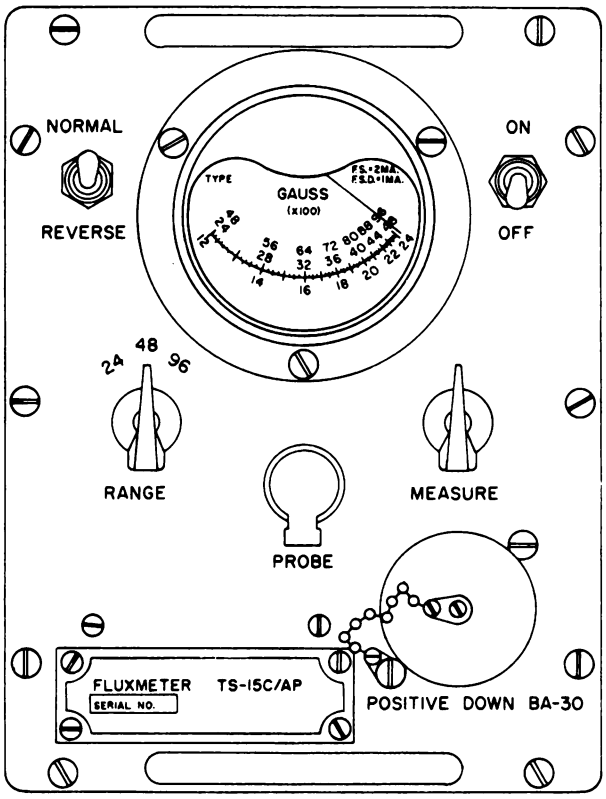

Figure 2-36. Front panel of fluxmeter TS-15C/AP.

2. Describe the difference between the gaussmeter and a standard Weston movement.

3. How are the two meters arranged in the circuit in relation to each other?

435. Outline the steps in the procedure for testing a magnetron magnet.

Flux measurement. Before flux can be measured, the magnet and magnetron must be separated. In some systems, the magnet is on hinges and is simply swung away from the magnetron. In some others, the magnetron must be physically removed. (Obviously, magnetrons with integral magnets cannot be tested with a fluxmeter.)

To prepare for the test, initially set the fluxmeter to its highest range (fig. 2-35) and connect the probe meter. Then, using the yoke assembly, position the probe meter between the poles as in figure 2-36. If the gaussmeter deflects the wrong way, change the position of the NORMAL/REVERSE switch. Adjust the MEASURE control until the needle of the probe meter is on its midscale reference mark. If the reading of the gaussmeter is inadequate, set the controls for a lower range and repeat the adjustments.

Exercise (435):

1. Outline the procedure for testing magnets in three essential steps.

436. Given the conditions of measurement, determine the flux density of a magnetron magnet.

Interpretation of meter reading. Flux densities for magnets used with magnetrons commonly range from 1000 to 6000 gauss. Magnetron size and frequency are the principal determinants of required flux density. The magnet used in MPS-9 system should have a strength of about 2000 gauss. On the meter of figure 2-36, this would be a reading of 20 on the bottom scale. To be correct, all the meter readings must be multiplied by 100.

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Exercise (436):

1. With the probe meter reading at its center-scale reference mark, the gaussmeter in figure 2-36 also reads center scale. If the RANGE switch is set to 24, what is the magnet's strength?

437. List and describe at least three possible causes for loss of magnet flux.

Loss of magnet flux. One would suppose that a magnet, because of its solid structure, would be virtually indestructable. In reality, they are easily damaged—not necessarily in the physical sense but in their magnetic strength. A loss of flux can happen in a variety of ways. The most subtle of these occurs when the magnet is stored close to other objects made of ferromagnetic materials. Whether in a warehouse or a maintenance shop, such magnets must be stored apart from steel tools, mechanical assemblies, metal workbenches, etc. Keepers must be left in place between the poles until such time that the magnet is installed. When handled, gentleness must be the rule. Magnets are heavy and sometimes difficult to handle, but they must not be dropped nor thrown about, for severe physical shock will quickly demagnetize a magnet.

Although serious, storage and handling problems are insignificant when compared to the magnet damage caused by careless installation and maintenance. The chief culprits are steel tools such as wrenches and screwdrivers that are jerked against the magnet's poles. The single collision between a screwdriver and the magnet may decrease the flux level of the magnet by as much as 3 percent (and may smash the fingers holding the screwdriver by as much as 100 percent.) Accordingly, only bronze tools especially made for use around magnets should be used.

Exercise (437):

1. Identify three sources of magnet damage and briefly describe the reason each affects magnet strength.

438. From a series of statements about procedures for removing and replacing a magnetron, select those that are correct.

System Maintenance. Earlier in this chapter, we talked about protective devices for transmitter-modulator circuitry. It was evident the voltages used in radar transmitters require the repairman to use sound safety practices when performing maintenance on transmitting equipment. Here, we will discuss the procedures involved in replacing transmitter magnetrons and the effects that mishandling has on them.

Magnetron replacement. The very first thing to say about magnetron replacement concerns safety. All power to the transmitter-modulator assemblies should be removed and all high-voltage storage elements grounded by a shorting stick. Only then should you begin removing the panels and assemblies that will allow you access to the magnetron. When accessible and prior to removal, thoroughly clean the general area around the magnetron so that dirt won't get into the waveguide sections and connectors. The choice of cleaning agents is important—nothing should be used that could introduce iron or steel particles into the area of the magnet.

Begin removal by disconnecting the input filament and high-voltage leads and coaxial connectors. Then, using nonmagnetic tools, remove retaining hardward and, finally, the magnetron. Inspect the magnetron blower and remove any accumulation of dust. Also, investigate the condition of RF joints, connectors, and coaxial bullets for signs of corrosion or burning, and clean as necessary. If the magnet is a separate assembly, check its poles for loose hardward and metal fragments.

Before installing a new magnetron, it should be given a continuity and short test with an ohmmeter. Then, remove dust covers and magnet keepers (if any) and install. Make sure that coaxial or waveguide couplers and magnetron tuning drive are properly mated before reinstalling any hardware. Use the nonmagnetic tools to reinstall the bolts and lockwashers. If any small parts are dropped, they will probably end up attached to some part of the magnet. Finally, reconnect wiring such as filament and ground leads.

After the magnetron is reinstalled and power applied, preliminary checks and alignments should be accomplished during the time-delay warmup. If the installed magnetron is new or one that has been stored for a long time, expect erratic operation when high voltage is first applied. Most such magnetrons contain small amounts of gas that can cause arcing, but cleanup of this gas is usually possible by following a break-in procedure. Apply high voltage at a low level and then increase it to the point where sporadic arcing begins. Within a short time, the rate of arcing should decrease. When that occurs, the high voltage can be increased until the rate of arcing again increases. Such incremental increases should be continued until the magnetron reaches a stable condition at the normal operating point. Once this point has been reached, the correct operating level should be maintained for the remainder of magnetron life.

Exercises (438):

Answer the following with a T if true or an F if false.

___1. Steel wool should be used to remove dirt and corrosion from transmitter surfaces.

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___2. The choice of tools is an important preliminary to magnetron replacement.

___3. If a newly installed magnetron arcs, it should be removed and discarded.

___4. High voltage to a new magnetron should be increased gradually.

439. State at least three types of magnetron failure resulting from mishandling.

Effects of mishandling. It is a fact that a great number of magnetrons are destroyed through careless handling and storage practices between factory and radar transmitter. Certain types of damage reoccur all too frequently. Most common is the loss of vacuum caused by cracked or broken glass and ceramic windows. If the magnetron is dropped hard enough to distort the anode block, the frequency stability will be affected, and occasionally the tuning mechanism will become inoperative. A variation will cause the cathode to short out to the anode block.

Some of the damage is beyond the control of the radar repairman, but he can make sure that he is not the cause if he will practice commonsense handling of magnetrons in the maintenance shop. Figure 2-37 shows the typical protective packaging of a magnetron. It should be kept in such a container until needed and should be returned to one if removed from the transmitter. Tossing loose magnetrons into storage bins is just bad news. There they are subject to damage by dirt and corrosion, as well as the various types of impact damage previously cited. Remember, magnetrons may look sturdy, but they are, after all, vacuum tubes and must be treated as such at all times.

Exercise (439):

1. In three short statements, state possible results of severe mechanical shock on a magnetron.

440. Given general symptoms of transmitter system malfunctions, state the most probable general cause of a failure.

Troubleshooting Procedures. Troubleshooting the transmitter may be one of the most trying experiences you encounter as a repairman. Because of the voltages involved, the number of test points is quite limited; the physical size and locality in some systems restrict your accessibility to the equipment. All of these things increase the difficulty of troubleshooting. Here, we will limit our discussion to the most common failures and to the ways you can detect these problems.

Transmitter troubleshooting. At 0400, Jones gave up, called the "Boss" and said, "I've checked everything, but I can't get the transmitter to work. The "Boss" came to work in his pajamas and replaced the blown fuse that had caused the failure. Jones took the predictable, but unmerciful, chewing-out like a man. The ribbing he took when the story got around was worse. A painful experience, but it caused Jones to begin some serious thinking about methods for troubleshooting transmitters and other high-voltage circuits. Also, the "Boss" decided that some OJT was in order. So, during succeeding days, Jones heard all he ever wanted to know about troubleshooting, but had been afraid to ask, and then some. The next time

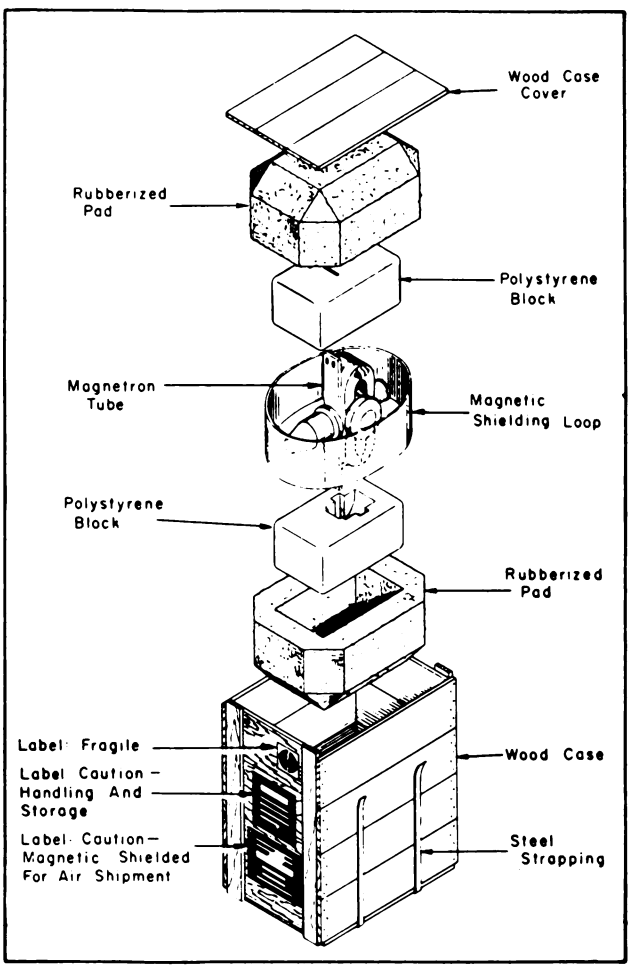

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Figure 2-37. Packaging details for air shipment of a megnetron.

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a fuse blew at midnight, Jones replaced it and the "Boss" slept well and smiled a lot the next day.

A true story? Not really; but most apprentice repairmen have suffered through some variation of this theme. Like touching a hot stove, learning follows pain. What is learned can be summarized in two statements. First, to be routinely successful, troubleshooting must be done methodically, not checking everything one can think of. Second, the simple troubles are much more common than the complex ones, which translated means that the blown fuse is more common than the burned-out transformer.

Let's put this at a practical level by examining a few problems frequently encountered in a transmitter system and some of the defects that can cause them. The most common is encountered when the high voltage is turned on and nothing happens. Sure, it could be the power supply—but that's not likely. Much more probable are such easily remedied defects as open interlocks, missed control switches, and blown fuses. Usually, meters and lights can tell much about the condition of control circuits, but you must be able to interpret their indications.

In a second group of commonly encountered troubles, high voltage can be turned on, but no rectifier current is indicated on the power supply meter. Certainly the thyratron is not firing—but why? Before you replace the thyratron, check the system's trigger and modulator driver trigger. In most such cases, you will restore transmitter operation by repairing a defect in the trigger-generating circuits. Thyratrons do go bad, as do pulse-forming networks, charging chokes, and pulse transformers. Any of these can cause the indications, but here again, the statement about first looking for the easy and obvious bears repeating.

In a third group of troubles, excessive rectifier current causes the overload relay to trip, sometimes so quickly that no meters or indicators can be read. Generally, three factors will cause overload tripping, excessive duty cycle, impedance mismatch, and failure or high-voltage breakdown of a component.

Component failures are often difficult to isolate. As in other circuits, tube failures are most common. However, tubes such as thyratrons and magnetrons cannot be tested with conventional equipment, so replacing a suspect tube with a *known* good one is the only reliable method of testing them. Substitution should only be done when all indications and tests point to a specific tube as the culprit. If such substitution does not restore operation, then the original tube should be reinstalled.

In those instances where a tube is not the cause of failure and performance tests do not provide adequate clues, it will probably be necessary to remove the assembly from the equipment rack for testing of individual parts. Continuity tests can be done reliably with a high-voltage test set. The MD-1 is typical. It has a maximum voltage output of 10 kilovolts, so all high-voltage safety rules must be rigidly obeyed during testing. The uncompromising use of a shorting stick is especially important. A 10-kV charge left on a large capacitor could be instantly fatal to the unwary.

Exercises (440):

1. HV is on, but panel meters indicate no rectifier or magnetron current. What should you check first?

2. The HV READY light is lit, but nothing happens when the high-voltage is turned on. What is probably wrong?

3. What is the best method for checking the condition of a thyratron?

4. How can the high-voltage insulation of a PFN be tested?

441. From indications obtained with an echo box, state the most probably general cause of a failure.

Troubleshooting with synchroscope and echo box. Many troubles within transmitter systems are complex and difficult to diagnose. For many of these, the echo box can provide valuable clues. To a great extent, using the echo box in this way requires the repairman to know what is normal. Since this varies from set to set, it is difficult to pin down all possibilities. However, some troubles can be generalized. Figure 2-38 is an attempt to present a few of the more common ones. Note that both echo-box meter readings and synchroscope ringtime indications are treated. Even when one is normal, the other may clearly show a defect.

Exercises (441):

1. Which of the spectra in figure 2-38 corresponds to erratic echo-box ringtime, but steady echo-box meter reading?

2. If echo-box meter reading and ringtime are affected only when the antenna is rotating, where is a logical place to look for the trouble?

442. From a list of possible effects, select those that can result from poor TR recovery time.

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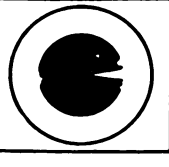
EFFECT	APPEARANCE ON RADAR INDICATOR	APPEARANCE ON ECHO BOX METER	PROBABLE CAUSE
RINGTIME AND TEST SET OUTPUT SATISFACTORY			RADAR PERFORMANCE SATISFACTORY
RINGTIME LOW, OUTPUT READING SATISFACTORY			RECEIVER TROUBLE: DETUNED MIXER OR LOCAL OSCILLATOR. BAD CRYSTAL, EXCESSIVE I-F NOISE. ADJUSTMENT OF PROBES IN MIXER CAVITY DETUNED T-R BOX
RINGTIME LOW, TEST SET OUTPUT VERY LOW			LOW POWER OUTPUT, CHECK SPECTRUM
RINGTIME LOW, TEST SET METER READING LOW			TROUBLE PROBABLY IN TRANSMITTER AND RECEIVER AND/OR TROUBLE IN TRANSMISSION LINE
RINGTIME ERRATIC, TEST SET METER READING STEADY			TEST SET DETUNED. BAD PULSING, DOUBLE MODING TRANSMITTER, OR LOCAL OSCILLATOR POWER SUPPLY TROUBLE. CHECK SPECTRUM
RINGTIME ERRATIC, TEST SET OUTPUT READING ERRATIC.			FAULTY TRANSMISSION LINE ON CONNECTION CONDITION WORSE WHEN LINE IS RAPPED
END OF RINGTIME SLOPES GRADUALLY, PERHAPS EVEN EXCESSIVE RINGING. GRASS APPEARS COURSE. TEST SET OUTPUT READING STEADY AND SATISFACTORY.			OSCILLATING I-F AND/OR NARROW BAND RECEIVER
PRONOUNCED DIP IN RINGTIME AT END OF PULSE.			FAULTY TR OR DUE TO RECEIVER GATING ACTION
RINGTIME VERY SLIGHTLY LOW, POOR OR BAD SPECTRUM		POOR SPECTRUM	TRANSMITTER TROUBLE
BLANK SPACES OR ROUGH PATTERN ON PPI RINGTIME INDICATOR, TEST SET OUTPUT READING VARIES AS RADAR ANTENNA IS ROTATED.			FREQUENCY PULLING OR TRANSMITTER DUE TO BAD ROTATATING JOINT OR TO REFLECTING OBJECT NEAR RADAR ANTENNA.

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Figure 2-38. Echo box indication of radar troubles.

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TR recovery time test. The duplexers just presented contain TR tubes, and, therefore, all have a common maintenance problem: TR tube failure. The following paragraphs will first present some of the significant symptoms and effects of TR failure and will then detail how the condition of a TR can be determined with a simple, reliable test.

As a TR tube ages with extended use, its ionization and recovery times gradually increase. The former is most serious, for the increased ionization time allows power to leak through the TR into the input circuits of the receiver. Because of their delicate structure, the circuit elements most vulnerable to damage are the diodes in RF amplifier and mixer circuits. In early stages, TR failure causes a gradual reduction in receiver sensitivity. Should the degree of TR failure be allowed to progress, the signal mixer diodes will deteriorate rapidly.

Complete TR failure, perhaps caused by a cracked glass window, can cause severe arcing when the transmitter is turned on and nearly instant destruction of receiver diodes.

Increased recovery time lengthens the minimum range resolution of the radar. Received signals cannot pass into the receiver through an ionized TR, so echos from close-in targets are lost.

Exercise (442):

1. Which of the following may indicate a defective TR tube?
   a. Frequency instability.
   b. Arcing with antenna rotation.
   c. Loss of receiver sensitivity.
   d. Failure of mixer diodes.
   e. Fading of echo signals from aircraft approaching the radar.
   f. Fading or loss of distant echo signals.

443. Outline the basic steps in measuring TR recovery time using an RF pulse.

Procedures for TR recovery time test. Measuring the ionization time of a TR cannot normally be done in a field situation. However, increases in ionization and recovery time tend to occur together as a TR ages, and the recovery time is easy to measure by the method illustrated in the waveforms of figure 2-39.

An RF pulse from a signal generator is applied into the directional coupler and then displayed as video on a test oscilloscope along with the transmitter pulse (main bang) and target video. The pulse delay control on the signal generator is used to position the test pulse well back from the transmitter pulse in an area of ground clutter or other video. The output from the signal generator is adjusted to a level well below the saturation level of the receiver, as in figure 2-39,A. Then the oscilloscope's vertical controls are adjusted for a test pulse that is 1 inch in amplitude.

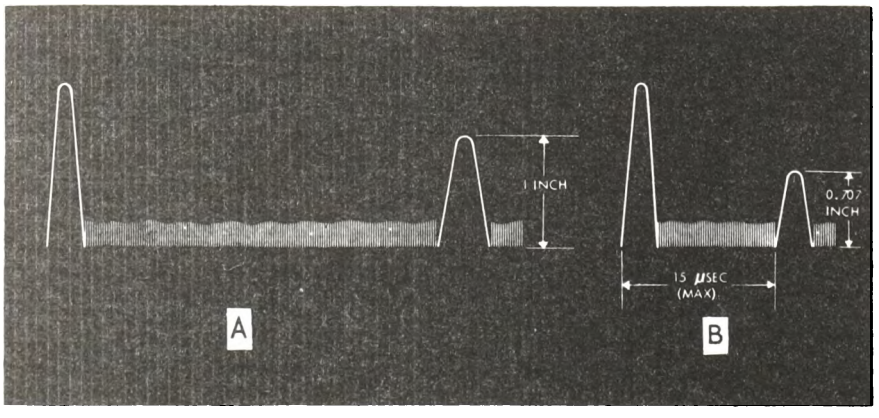

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Figure 2-39. TR recovery.

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The delay control is then rotated to move the pulse toward the transmitter pulse. At some point, the amplitude of the test pulse will begin to decrease as it enters the region of TR ionization. When it has dropped to an amplitude of 0.7 inch, measure the time interval between transmitter and generator pulses as in figure 2-39,B. 0.7 volt corresponds to the half-power point (a 3-dB reduction in target strength).

The maximum allowable time duration for TR recovery varies from one radar to another. Measurements exceeding TO performance standards usually indicate that TR tube replacement is in order.

Exercises (443):

1. Outline the procedure for measuring TR recovery time using an RF pulse.

2. Why is the pulse moved toward the main bang until it drops to 0.7 volt?

444. From specified indications, identify the probable source of failure in the RF system, and state what is used to identify the source of failure.

Maintenance of RF systems. Most RF transmission systems are relatively trouble-free when compared to the electronic circuits that precede or follow them. Nevertheless, they do sometimes present unique and difficult-to-diagnose problems. Most of these in some way involve mismatches of impedance but only rarely are they caused by something "wearing out." More common are physical damage, corrosion, and failure of electronic parts.

Several indications can point to the RF transmission system as the location of a trouble. Among these are the obvious, such as high VSWR measurements, and the more subtle, such as weak video, that cannot be explained by decrease in transmitter power or receiver sensitivity. For instance, if the inside of the waveguide is badly corroded from exposure to dirt and moisture, the magnetron's output power can be dissipated before it can be radiated. This is sometimes the case even though tests may indicate normal transmitter power.

Physical damage to RF systems can occur in a number of ways. Waveguides are sometimes dented by careless handling of assemblies. Choke joints are damaged by improper installation of hardware. However, not all failures in the RF transmission system result from poor maintenance practices. In some, the failure is a secondary byproduct of a more serious failure in drive motors or bearings that produces excessive mechanical vibration. Stresses and structural fatigue from long-term exposure to vibration can break apart both rigid and flexible waveguides.

Detection of failures in the RF transmission system depends upon correct interpretation of system performance checks such as power and VSWR measurements and spectrum analysis. In addition, TOs provide specific radar tests to evaluate the condition of each of the major components in the transmission system. Many of these procedures require use of a dummy load.

Exercises (444):

1. If power and sensitivity tests are normal, but video returns are consistently weak, what in the RF transmission system could be the cause of the trouble?

2. What item of specialized test equipment is of greatest value in locating RF transmission system failures?

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CHAPTER 3

Receiving Systems

FOR SOME maintenance personnel, the receiver system is the most interesting and challenging of all radar systems. The receiver, of course, plays a major role in determining the operational capabilities of any overall radar system. The receiver system also has some of the most critical circuitry you will be called upon to troubleshoot, maintain, and align. All radars, regardless of their specific function, contain common receiver components having the same operating principles.

3-1. Principles of System Design

In order that you may more fully understand the radar receivers designed to serve specific functions, we will first discuss the requirements affecting the design of a basic receiver and then the receiver components necessary for automatic tracking radar.

445. List the four main factors upon which the operating capabilities of a receiver depend and identify the effect that each has on receiver operation.

Basic Receiver Requirements. The operating capabilities of a receiver depend on:

- Noise.
- Gain.
- Tuning.
- Distortion.

Noise. Many people have the impression that the smallest usable receiver signal is limited by receiver gain ability. This is not so. The fundamental limit on the size of the weakest signal which can be detected is imposed by the appearance of "noise" in the receiver output. Although this noise cannot be heard, sources of the random voltage fluctuations that tend to hide the signal voltage are of the same nature as those that cause the noise in the output of an ordinary radio receiver. These disturbances, which appear on the radar indicator, as well as the voltage causing the disturbances, are referred to as noise. No matter what type indicator is used, if a signal is hidden by the noise on the indicator screen, no amount of increased receiver gain will make it visible. As an example, if the first stage in a receiver (the RF amplifier, when one is used) is generating noise, that noise is then amplified, along with the signal, throughout the receiver. Therefore, it is very important that the first stages in a receiver be as noise-free as possible. Once the signal becomes larger than the noise, it can easily override the noise and hence mask its presence. It, therefore, becomes evident that the signal-to-noise ratio of the receiver limits its operation.

The minimum signal-to-noise ratio which will allow the received signal to be seen is difficult to specify because of the many factors involved. Indicator sweep speed, type of scan, indicator screen persistence, and the operator's ability are some of the factors. Regardless of what factor we consider, the smallest usable signal is still determined by noise level rather than by receiver gain.

Gain. The gain required of a receiver depends mainly on the type of indicator system used. A-type indicators (position-modulated scan) use electrostatic cathode-ray tubes and require from 40 to 100 volts for a 1-inch deflection on the screen. (Remember, deflection alone does not aid materially in detecting weak signals in the noise.) A PPI indicator (intensity-modulated scan), on the other hand, requires only enough voltage to raise the control grid potential of the CRT above luminous cutoff, and pulses of about 20 volts are sufficient to produce bright spots on the screen.

Since the received signal at the antenna may be only 2 or 3 microvolts, a voltage gain in the range of 10^6 to 10^8 from antenna to indicator is required. One of the most serious difficulties to overcome in producing this large gain is that of feedback or regeneration. To overcome this difficulty, carefully shielding, decoupling between power supplies for the different stages, and amplification at different frequencies and in separate groups of stages are included in the receiver design.

Tuning. Because of temperature and loading variations causing frequency drift, it is impossible to maintain constant transmitter and local oscillator frequencies. In order to compensate for these frequency drifts, automatic frequency control (AFC) is usually included in radar receivers to provide a constant intermediate frequency (IF) to the receiver stages.

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Distortion. Since range accuracy depends on the time interval between a transmitted pulse and a received pulse, the receiver cannot be allowed to distort the received signal in any way which can affect this time interval. This is not to say that a certain amount of distortion relating to the pulse shape will not occur. For instance, if the envelope of a high-frequency pulse at the receiver input is rectangular, the output usually emerges as an unsymmetrical, rounded-corner pulse. The amount of distortion is closely related to the receiver bandwidth.

Exercises (445):

1. What are the four main factors that determine the operating capabilities of a receiver?

2. What factor determines the smallest usable signal in a receiver?

3. Which factor has the greatest effect on range accuracy?

4. What is the primary factor to consider in determining the gain that the receiver must have?

446. Provided a list of receiver unit functions, match each with the unit which accomplishes that function.

Basic Receiver Operation. Figure 3-1 shows a receiver which can suitably meet the basic requirements we have just discussed. The receiver is of the superheterodyne type which uses amplification at a frequency which is the difference between the reflected RF signal input and the local oscillator output.

The received signals enter the receiving system by way of the TR tube. In some radar systems, RF amplification may follow the TR tube before the signal is applied to the signal mixer. This provides amplification of extremely weak returns and increases the signal-to-noise ratio. In the systems that employ RF amplification, it is normally accomplished through the use of a parametric amplifier. Usually, the signal mixer is of the coaxial type, using a silicon crystal. At the mixer, the reflected RF signal is combined with the continuous-wave RF output of the local oscillator to form a heterodyned signal at the desired IF, usually 30 or 60 MHz.

The IF signal passes through several stages of IF amplification. The IF amplifiers develop most of

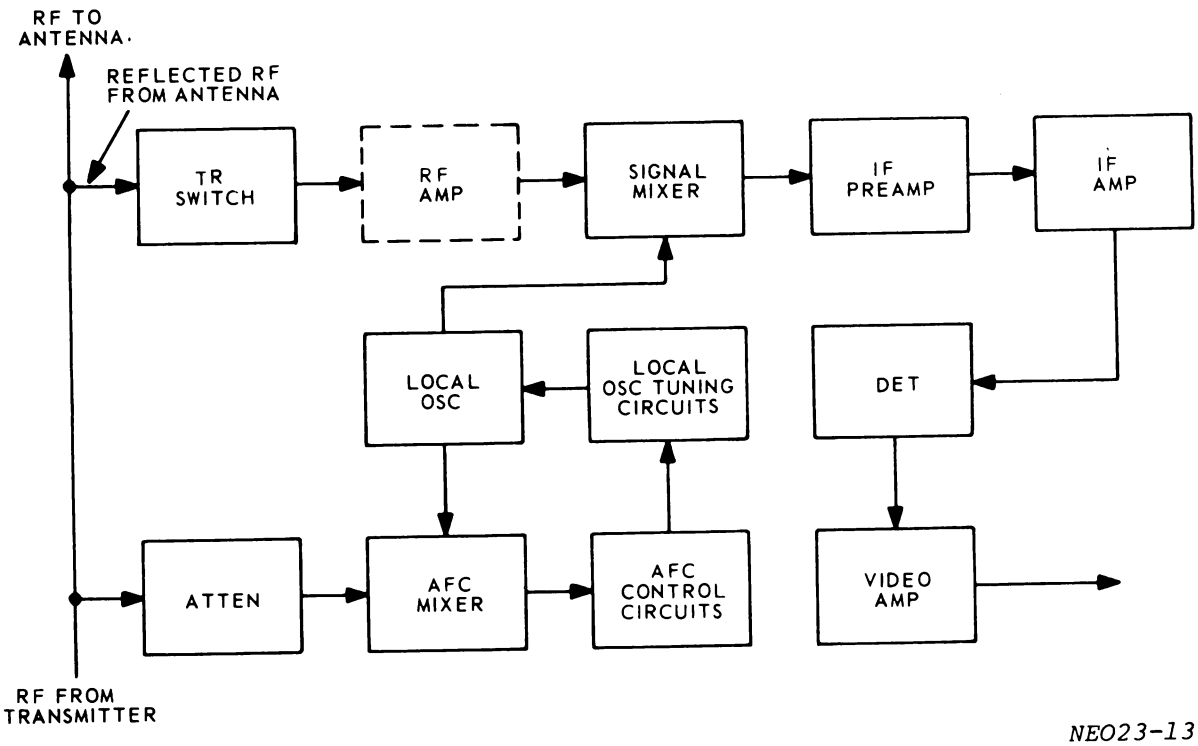

Figure 3-1. Typical radar receiver.

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the receiver gain and establish the overall receiver bandwidth.

The output of the IF amplifiers is sent to a detector, where it is rectified and demodulated before being sent through one or more stages of video amplification. The output stage of the receiver is usually a cathode follower in order to provide a low-impedance source for applying the video pulses through coaxial cable to the radar indicator(s).

The receiver is tuned by controlling the local oscillator frequency. Since this tuning is critical, and since the magnetron and/or local oscillator frequencies tend to drift, a form of automatic frequency control (AFC) is essential in order to avoid constant manual tuning. AFC is initiated by mixing an attenuated portion of the transmitted signal with the local oscillator signal to form an IF signal. The IF signal is then applied to a frequency discriminator, tuned to the required IF, which develops a control voltage that is applied to the local oscillator in order to maintain the correct frequency.

This, in general, is how a basic superheterodyne radar receiver operates. While our autotrack radar systems use superheterodyne-type receivers, these receivers have individual features not mentioned in the preceding discussion, as well as various other stages designed to meet the functional requirement of the associated radar.

Exercise (446):

1. Match the terms in column A with the most appropriate definitions in column B by writing the correct letter in the blank provided. Definitions may be used once only or not at all.

Column A	*Column B*
_____ 1. TR switch.	a. Combines the received signal with the local oscillator signal to form the IF.
_____ 2. RF amplifier.	b. Demodulates the IF.
_____ 3. Signal mixer.	c. Amplifies the signal prior to applying it to the indicators.
_____ 4. Detector.	d. Prevents transmitted energy from entering the receiver.
_____ 5. Local oscillator.	e. Prevents received energy from entering the transmitter.
_____ 6. Video amplifier.	f. Provides a continuous-wave RF signal to the signal mixer.
	g. Provides amplification of extremely weak signals.

3-2. Receiver—Radar Operation

Some autotrack radars have beacon operational capabilities in addition to their normal radar receiver capability. Beacon operation has intentionally been omitted in previous discussions, since the primary system affected is the receiver. In beacon operation, the ground radar transmitter pulse is accepted by the beacon receiver (installed in the aircraft) and amplified. The amplified pulse causes the aircraft's beacon transmitter to fire and send a pulse back to the ground radar. In order to accomplish this, the beacon receiver must be tuned to the ground radar transmitter frequency, and the ground radar receiver must be tuned to the beacon transmitter frequency. To allow us to quickly switch from radar to beacon operation, these systems use two separate local oscillators (radar and beacon), two separate AFC mixers (radar and beacon), and a 3-dB hybrid coupler. In the following discussion, we will divide the receiver operation into two modes: normal radar operation and beacon operation.

Let's closely examine the radar block diagram in figure 3-2. As shown, some of the blocks contain diagonal lines, some are solid and others are white. The diagonal line blocks are used only during normal radar receiver operation. The solid blocks are used only during beacon operation, and the white blocks are common to both radar and beacon operation.

The circulator, along with the TR tube, performs as a duplexer. The reflected (received) RF energy enters port 2 of the circulator, travels to port 3, and through the TR tube to the parametric RF amplifier.

447. Given a list of parametric amplifier component functions, match each with the component which accomplishes that function.

Parametric Amplifier. The use of an RF amplifier in the RF system is relatively new in the automatic tracking field. Conventional amplifiers, because they use resistors and tubes or transistors, develop considerable noise which limits the sensitivity of the receiver. A signal, in order to be reproducible for viewing on an indicator, must overcome the noise developed by the amplifier. The parametric amplifier (paramp) operates on the principle of varying capacitive reactance. The design of this amplifier is such that both the input and output are on the same line (see fig. 3-3). This characteristic has led to its being referred to as a reflection-type amplifier.

The paramp is connected to the main line by a circulator-coupling network, which operates in principle the same as the circulator duplexer discussed in Chapter 2. This circulator is smaller than the circulator duplexer because it is not required to handle as much power. This circulator, which is considered to be a part of the paramp, isolates the varactor diode from the input and output connections. It also directs the noise voltage fluctuations (mixer noise at port 3) into port 4 and the dummy load where they are dissipated.

The principal component in the paramp is the varactor, a PN-junction diode, which is reverse-biased. By varying the reverse bias applied to the varactor, we can vary the barrier junction and thereby vary the capacitive reactance.

In order to better understand the operation of the varactor, let's review some of our fundamentals. Recall that the charge (Q) on a capacitor is expressed by:
pressed by:

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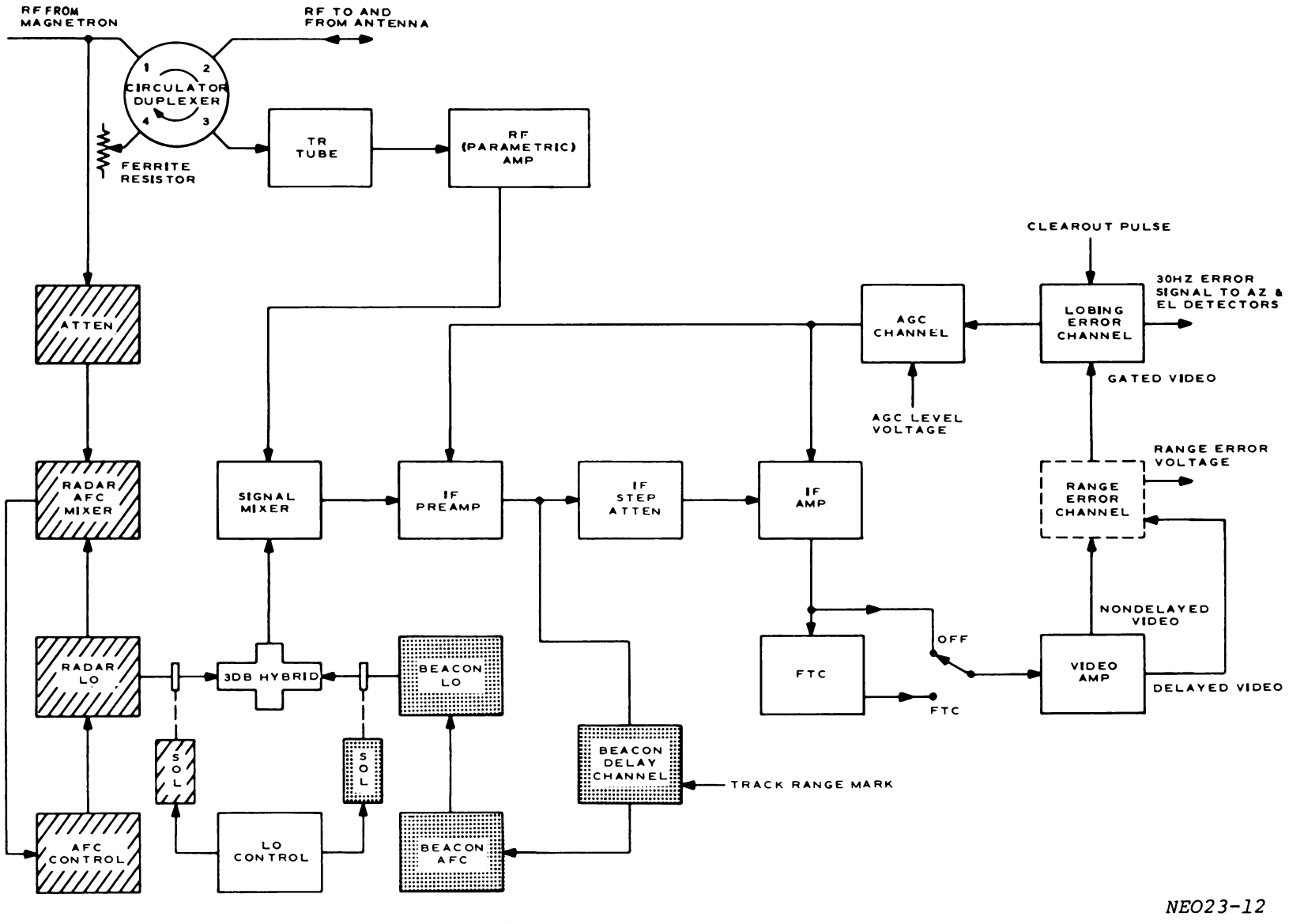

Figure 3-2. Autotrack radar receiver.

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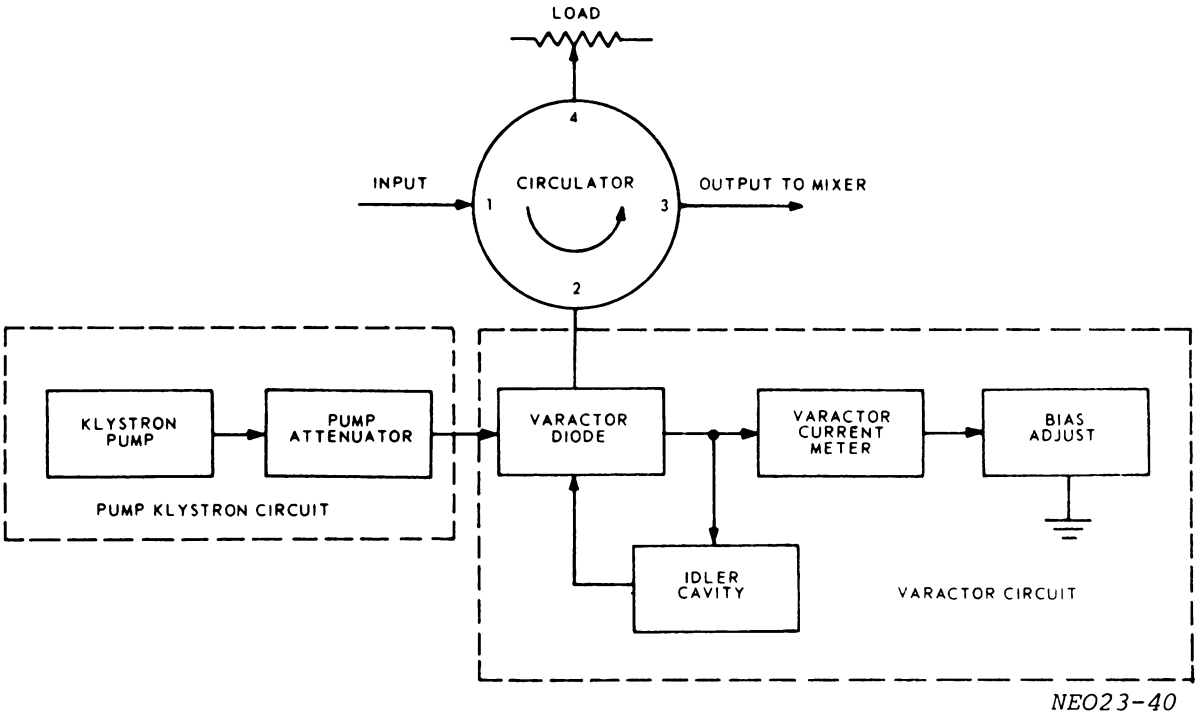

Figure 3-3. Simplified block diagram of parametric amplifier.

$$Q = CE \text{ or } E = \frac{Q}{C} \quad (1)$$

In equation (1), C is the capacitance in farads and E is the voltage across the capacitor. Let's assume that a variable capacitor has received a charge and there is no discharge path. If we increase the distance between the plates of the capacitor (decrease capacitance), voltage must increase in order to maintain equation equality. The power stored in a capacitor is expressed by:

$$P = \frac{CE^2}{2} \quad (2)$$

You can see that if the capacitance in equation (1) is reduced to half of its assigned value, the voltage is doubled. By assigning these new values to C and E in equation (2), you see that the power has been doubled.

Pump signal. If reverse bias is applied to the varactor in such a manner as to cause the capacitance to decrease at the time the input signal is at or near its peak voltage, you can readily see that amplification of the voltage across the varactor (input signal) results. The reverse-bias voltage causing the varying reactance is called the pump signal, and it is generated by a klystron oscillator. The pump signal must be at a much higher frequency than the input signal. We will learn why a little later.

A mixing action takes place within the paramp much in the same manner as it does in a mixer or converter. Four frequencies exist in the amplifier. They are the two original frequencies, pump signal and input signal—their sum frequency and their difference frequency.

Idle signal. The sum frequency has no path for propagation and is therefore suppressed. The difference frequency is called the idle signal and is combined with the input signal to place a distorted charge across the varactor. The phase of the idle frequency is always such that the varying charge placed across the varactor allows the pump signal to add power to the input signal.

Now we can begin to see why the pump signal must have a much higher frequency than the input signal. If the pump frequency were only twice the frequency of the input signal, the idle signal would be the same as the input frequency. The higher the pump frequency, the higher the idle frequency and, therefore, the higher the gain of the amplifier. This happens because the coincidence of the maximum positive and negative peaks of the input signal and the minimum capacitance of the varactor occur more frequently at higher frequencies than at lower frequencies. Keep in mind that it is the pump signal from the klystron oscillator that varies the capacitance of the varactor, and the combined input signal and idle signal that place the charge across the varactor. Varying the pump power controls the gain of the paramp.

Figure 3-2 shows that the output of the parametric amplifier is sent to the signal mixer. This output signal

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has been increased by at least 17 dB as a result of the amplification within the paramp.

Exercise (447):

1. Match the functions in column A with the appropriate terms in column B by writing the correct letter in the blank provided. Terms may be used once only or not at all.

Column A	*Column B*
_____ 1. Generates the reverse-bias voltage used to vary the reactance.	a. Circulator.
_____ 2. Its output combines with the input signal to vary the charge placed on the varactor.	b. Pump klystron.
_____ 3. Isolates the parametric amplifier from the input and output connections.	c. Varactor diode.
_____ 4. Combines the signals within the parametric amplifier and produces the amplified output.	d. Idler cavity.
_____ 5. Establishes the initial operating point of the varactor diode.	e. Bias adjust.
	f. Pump attenuator.

448. Identify the input and output signals of the two types of signal mixers and explain the operation of each type of mixer.

Signal Mixer. When the RF amplifier is not used, the signal frequency mixer is the first stage of the receiver to act upon the received echo. This is the stage that converts the RF energy to IF energy. The mixer is identified as the first detector in the radar set. The RF signal and a local oscillator frequency are mixed in a single-ended or in a balanced crystal mixer.

Crystals are used because of their low losses at high frequencies, low inherent noise, and small size. A disadvantage of the crystal is its lack of gain. But the advantages outweigh the disadvantages, so crystal mixers are used in most radar receivers.

In radio, the mixer and local oscillator stages are usually combined in the same tube. In radar, the mixer is a completely separate stage from the local oscillator. The oscillator input will be mentioned as the mixers are discussed, but its operation will be discussed later.

Single-input mixer. The single-input mixer has both the RF and local oscillator input signals applied between the electrodes of a single crystal. This type of mixer is most commonly used with receivers operating with a wavelength of 10 cm and not using a velocity-modulated-type local oscillator (refer to fig. 3-4). One input to the mixer comes from the TR cavity or the RF amplifier. This enters point A and is applied to the crystal. The other input from the local oscillator enters point B and is applied to the crystal. Both signals affect the conduction of the crystal. The amount of local oscillator signal coupled into the mixer (point B, fig. 3-4) is variable and basically controls the mixer current. This coupling is adjusted so that the crystal output current meets the required level of the individual radar set. This is to assure that the crystal is operating in the nonlinear portion of its characteristic curve. Operation in this portion of the curve results in the heterodyning action required for proper operation. The difference between the RF signal frequency and the local oscillator frequency is coupled out as the IF. This IF signal in most cases is applied to an IF preamplifier. Some sets have the mixer located physically very close to the IF amplifier and do not require the preamplifier.

The crystals used in the mixers are very sensitive to stray RF and are usually shipped and stored in lead containers. They are also very sensitive to differences in potentials, and you should be careful to first ground your hand to the mixer assembly before inserting the crystal.

Balanced crystal mixer. To reduce noise from the local oscillator, a balanced crystal mixer is used. Noise sidebands, above and below the output frequency, are contained in the local oscillator output. Any of these signals, above or below the oscillator frequency by the amount of the IF frequency, are detected by the mixer as an IF signal and presented to the next stage of the receiver. The balanced mixer suppresses these noise signals.

Several variations are possible in the construction of a balanced mixer, but they all have the same basic function of suppressing the noise generated by the local oscillator. This type of mixer uses two crystals. The noise suppression capability of the mixer depends upon the balance obtained between the crystals. One type of construction used is a multiarm waveguide section called a magic tee (look at fig. 3-5). Notice that the joints resemble the letter "T." In this circuit, the output IF is allowed to pass through a tuned IF transformer, while the noise generated by the local oscillator is effectively canceled because of the following action. The local oscillator input to arm 2 divides at the T junction and arrives at the two crystals in phase. The two crystals have equal conduction, and the difference in potential between points A and C of the output transformer is negligible. This effectively cancels the local oscillator signal and noise.

The RF signal enters arm 1 and arrives at the two crystals out of phase. This causes the conduction of the crystals to be unbalanced, and a difference in potential will exist between points A and C of the output transformer. The RF signal that causes the mixer to be unbalanced is present at the crystals along with the local oscillator signal, and mixing action occurs. The secondary of the output transformer is tuned to accept the difference frequency. The difference in potential existing between points A and C of the transformer is, therefore, occurring at the difference frequency, or IF rate.

Exercises (448):

1. What are the input and output signals of each type of signal mixer?

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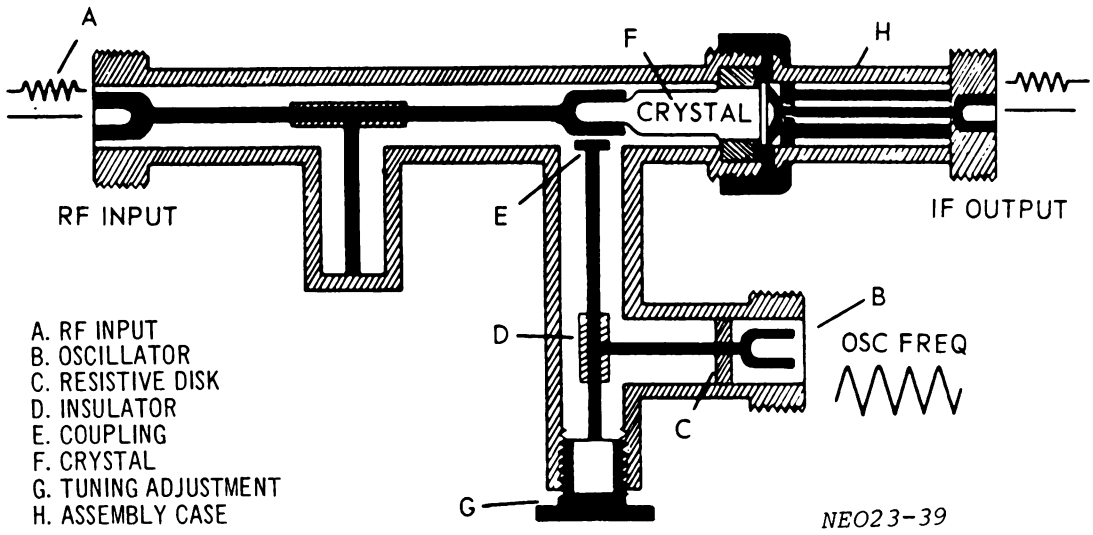

Figure 3-4. Typical single-input mixer.

2. On what basic principle does a crystal mixer work?

3. What is the major advantage of a balanced signal mixer?

4. What determines the noise suppression capability of a balanced signal mixer?

449. State the purpose of the local oscillator and explain its operation.

Local Oscillator. The local oscillator provides a continuous-wave RF signal to the signal mixer. This signal must be of a constant, controllable level output; as noise-free as possible; and maintain the proper separation with respect to the received RF signal. These requirements are necessary to assure proper operation of the signal mixer. The local oscillator output is fed directly to the signal mixer.

A velocity-modulated reflex klystron is normally used as the local oscillator. Manual tuning of the klystron is accomplished by varying the size of the cavity. Automatic tuning is accomplished by varying the negative potential on the repeller plate (refer to fig. 3-6). The output is loop-coupled from the klystron cavity and fed to the signal mixer. A portion of the local oscillator energy is also mixed with the magnetron energy to produce IF signals, which are used by the receiver for the development of the AFC to maintain the local oscillator frequency 60 MHz above the magnetron frequency.

Figure 3-7 is a simplified diagram showing voltage relationships at the mixer input and the resultant output. The RF signal and local oscillator signal may be considered to be in series and therefore appear as the difference at the mixer *output*. The unmodulated voltage from the local oscillator is shown in A, figure 3-7; the unmodulated RF signal is shown in B, figure 3-7. Remember that the local oscillator signal is in the order of volts, whereas the RF signal is in the order of microvolts (or in millivolts) and for illustration purposes has been greatly enlarged. The difference of the local oscillator and signal voltages (C, fig. 3-5) is shown by adding together, point by point, corresponding values of the two signals. Since the signal voltage is very small as compared with the local oscillator signal, the resultant difference signal is nearly sinusoidal. Let us assume that the local oscillator voltage is at 1060 MHz and that the RF signal is at 1000 MHz in a 1-μsec pulse. This varies the envelope of the resultant signal at a 60-MHz rate during the same 1-μsec period. Thus, the envelope varies at a frequency equal to the difference of the RF input and local oscillator signal frequency. Throughout the following discussion, assume that the value of the intermediate frequency is 60 MHz.

Exercises (449):

1. What is the purpose of the local oscillator?

2. To what frequency would the local oscillator be tuned for an IF of 30 MHz with an incoming RF signal at 2995 MHz?

3. Describe the output signal of the local oscillator.

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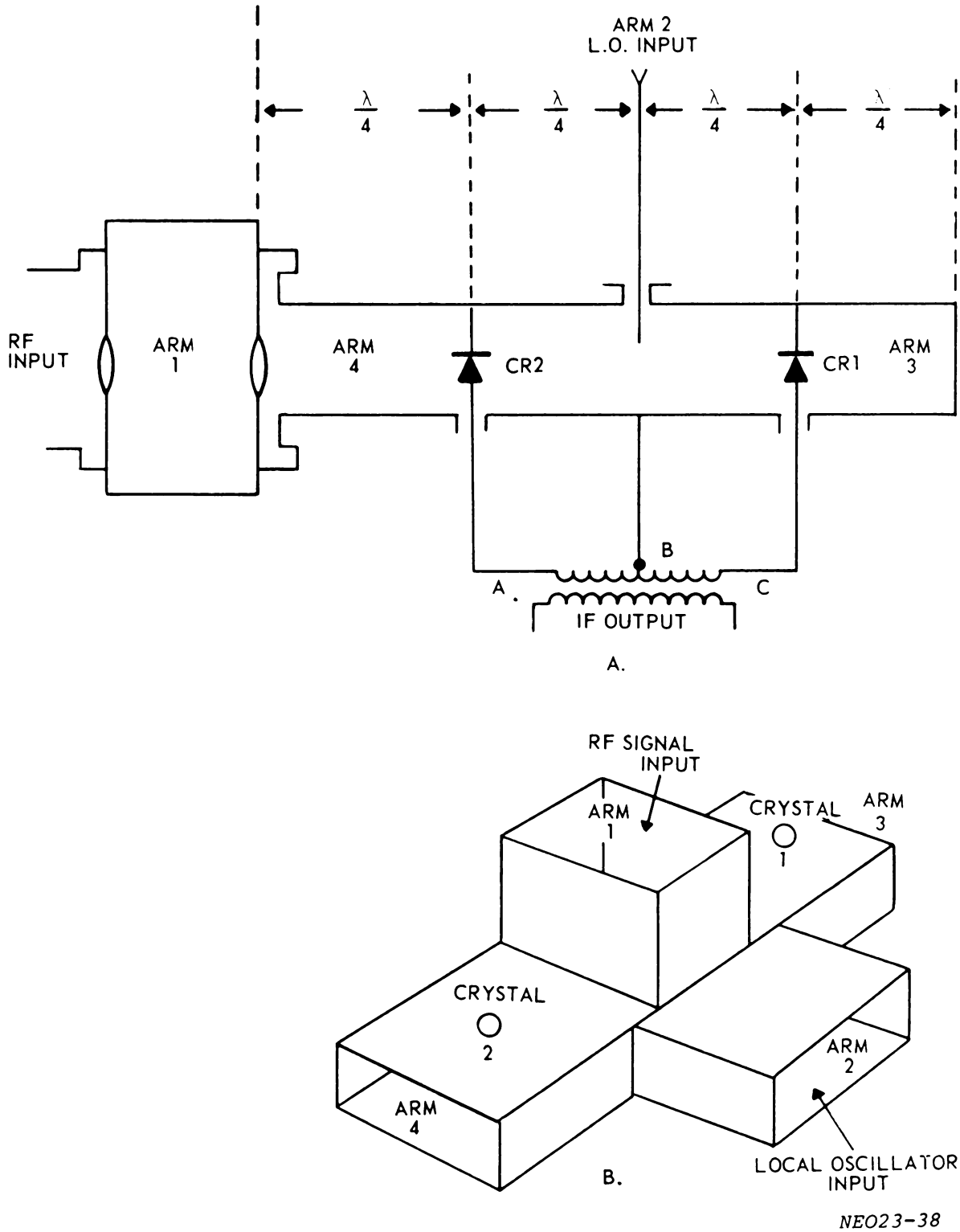

Figure 3-5. Balanced crystal mixer using a magic tee.

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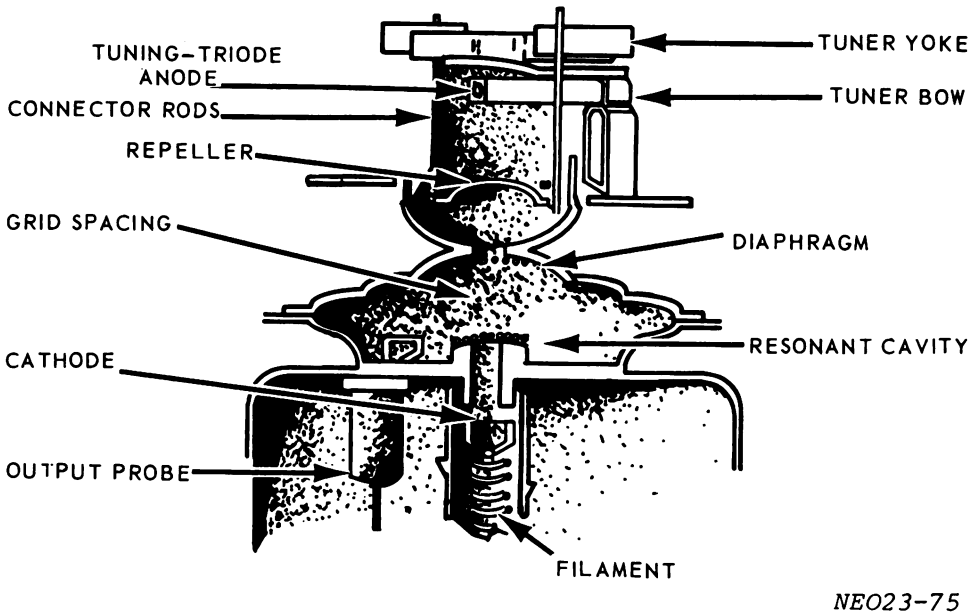

Figure 3-6. Reflex klystron.

4. How is manual and automatic tuning of the local oscillator accomplished?

450. List the three channels of the radar AFC and state the effect each has on the operation of the AFC unit.

Radar AFC. The radar AFC maintains the radar local oscillator frequency 60 MHz above the magnetron frequency. A reflex klystron is employed in the local oscillator which has a resonant cavity and tuning triode within the tube envelope. A view of the frequency-determining portion of the klystron is shown in figure 3-6. The AFC output, a DC voltage of either +20 volts or -30 volts, is applied to the tuning triode. The tuning triode then controls the cavity size of the klystron. In this manner, we control the local oscillator frequency.

Three channels are contained within the radar AFC unit, as shown in figure 3-8:

(1) Tracking channel.
(2) Searching channel.
(3) Feedback bias channel.

Tracking channel. This channel causes the radar local oscillator output to be approximately 60 MHz above the magnetron frequency. The channel consists of IF amplifiers V1 and V2, frequency discriminator V3, amplifier V4A, multivibrator V6, and clamper V8A, all of which are active when the radar local oscillator frequency is 55 to 65 MHz above the magnetron frequency. The IF input originates in the radar AFC mixer, is amplified by V1 and V2, and applied to frequency discriminator V3.

The discriminator transforms the IF signal into a bipolar pulse whose polarity depends on the IF. If the IF signal is below 60 MHz, the discriminator develops a positive pulse; if the IF signal is above 60 MHz, the discriminator develops a negative pulse. Amplifier V4A amplifies the discriminator pulse and sends it to V6, a bistable multivibrator which develops either +20- or -30-volt pulses. The +20-volt pulse is developed when the discriminator output is positive; the -30-volt pulse is developed when the discriminator output is negative.

V8A prevents the positive output of the multivibrator from exceeding +20 volts. This is to prevent the klystron-tuning triode from being overdriven during the downward frequency sweep.

Searching channel. The searching channel causes the radar local oscillator frequency to sweep up and down over a specified maximum range until the local

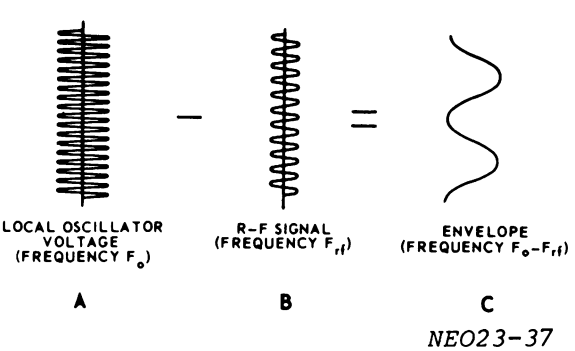

Figure 3-7. Signal mixer inputs and outputs.

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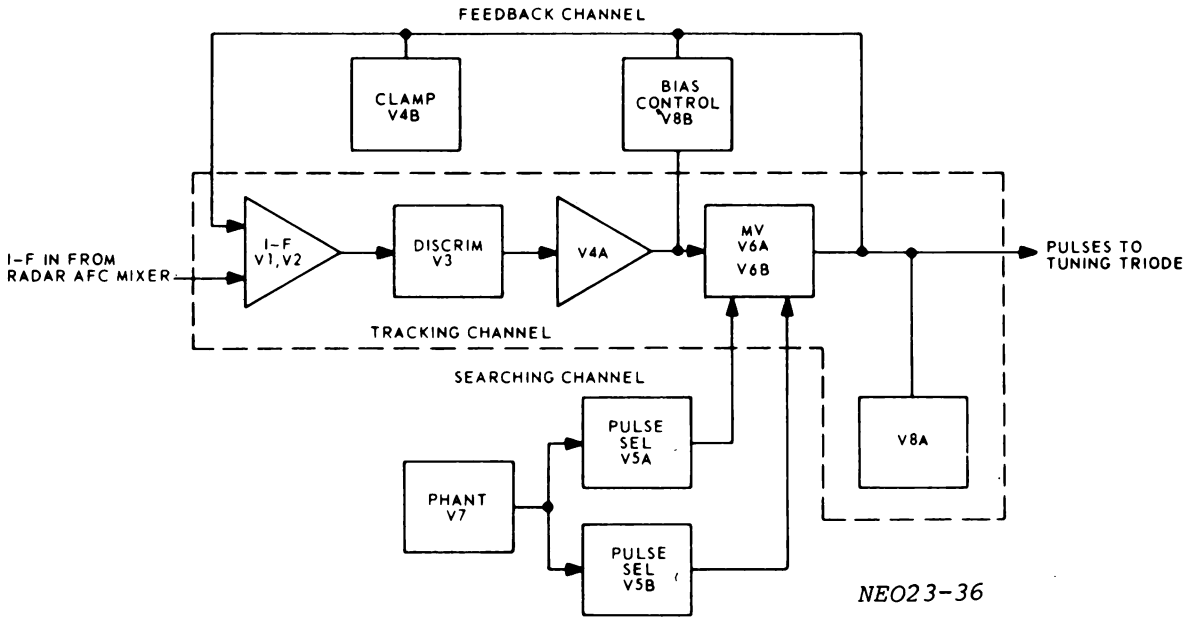

Figure 3-8. Radar AFC.

oscillator reaches a frequency 60 MHz above the magnetron frequency. At that time, the tracking channel assumes control. The searching channel consists of phantastron V7 and pulse selectors V5A and V5B.

Phantastron V7 generates a 100-volt, .5-sec pulse every 8 to 10 seconds. This particular phantastron differs from the basic phantastron in that no trigger is required for plate current flow, nor does it require fixed suppressor grid bias to cut off the plate current. Figure 3-9 shows the circuit and the related waveforms. Assume that C22 is charged to B+ and is therefore keeping plate current cut off because of the negative potential at the suppressor grid. During this time, heavy screen grid current flows. As C22 discharges through R34 to ground, the voltage developed across R34 is insufficient to keep plate current cut off. Once electrons are allowed to pass the suppressor grid, screen grid current rapidly decreases. This reduces the voltage drop across R30 and R31, causing C22 to begin recharging from ground, through R34 and R30, to B+. When plate current starts to flow, a voltage drop occurs across plate resistor R32. Since the charge on C23 cannot change instantaneously, this voltage drop appears at the control grid. C23 is now discharging through R33, R39, and back through the tube to the capacitor's other plate. This discharge causes the control grid potential to rise exponentially. As the control grid becomes less negative, plate current increases, thereby lowering plate voltage. This decrease in plate voltage is coupled back to the control grid to slow down its positive rise. This action continues until a point is reached at which any further change in grid potential does not increase plate current. Since beyond this point total tube current continues to increase, screen grid current must also increase. The voltage drop across R30 and R31, due to screen grid current, is coupled through C22 to R34, thereby againcuttingg off plate current. Capacitor C23 now charges to its initial value. C22 discharges through R34, and the cycle is complete.

Pulse duration is determined by the discharge time of C22. The time interval between output pulses is determined by the discharge of C23. Resistor R39 is adjusted so that the pulse interval is long enough for the radar local oscillator cavity to cool sufficiently and thereby allow a wider frequency range to be scanned. The phanastron output is differentiated and sent to pulse selectors V5A and V5B (fig. 3-8). Multivibrator V6 controls the bias conditions of V5A and V5B. When V6A is conducting, V5A is biased just below cutoff and V5B is biased more than 100 volts beyond cutoff. Therefore, the -100-volt pulse output of the phantastron triggers V5A but has no effect on V5B. This causes a negative pulse to be felt at the grid of V6A, causing it to cut off and V6B to turn on. This now biases V5A more than 100 volts beyond cutoff and V5B just below cutoff. When the next phantastron pulse is applied, V5B conducts and causes V6B to cut off. Thus, the multivibrator changes its state every 8 to 10 seconds, alternately applying +20 and -30 volts to the grid of the tuning triode.

Feedback bias channel. This channel (V4B and V8B) assures that the local oscillator will lock on to a frequency 60 MHz above the magnetron frequency rather than 60 MHz below the magnetron frequency. This is accomplished by biasing the IF amplifiers at cutoff during the time the phantastron output is causing the local oscillator to swing upward to a maximum frequency and allowing the IF amplifiers to conduct during the downward swing. In this way, the

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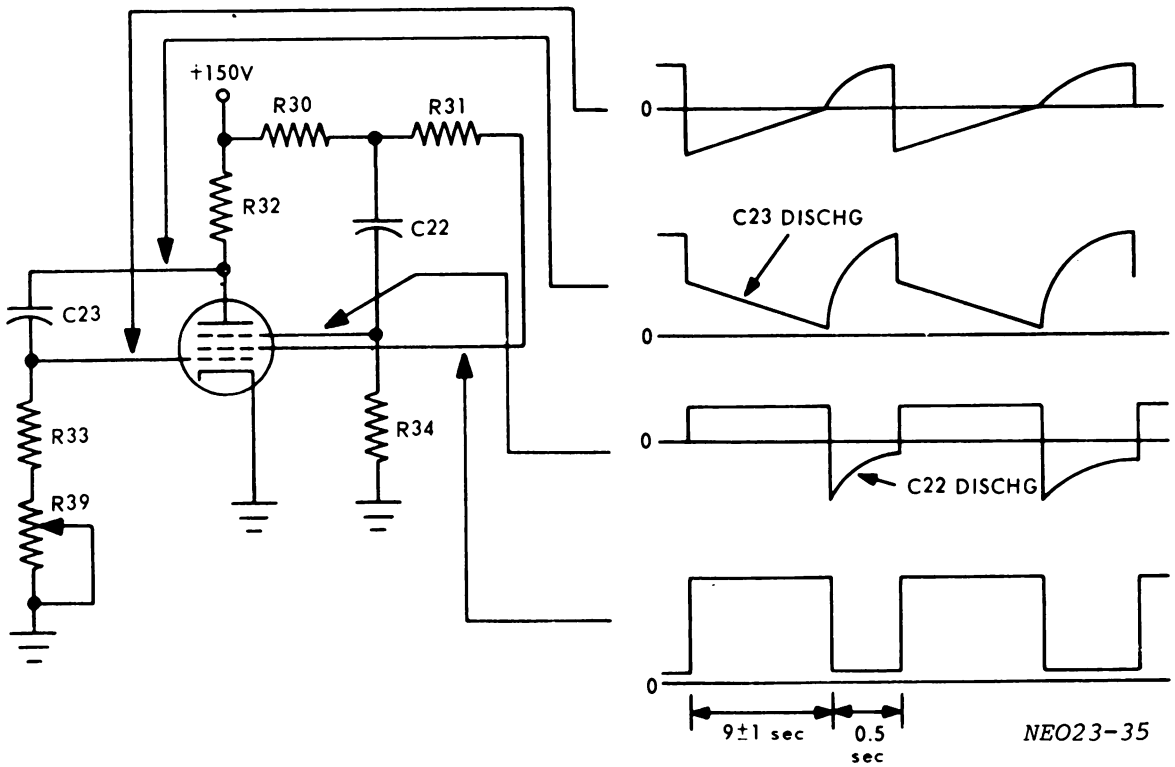

Figure 3-9. Phantastron circuit.

only IF signal that can be produced is that resulting at a frequency 60 MHz above the magnetron frequency.

Exercises (450):

1. Within how many MHz of the desired IF can the tracking channel of the radar AFC network detect IF signal variations?

2. With an input frequency to the AFC discriminator of 62.5 MHz, what is the voltage of the output pulses from the bistable multivibrator?

3. What effect does the feedback channel have on the operation of the radar AFC unit?

4. What are the three channels in the radar AFC unit?

451. State the purpose of the IF preamplifier and IF amplifier and identify operational characteristics of each.

IF Preamplifier. The purpose of the IF preamplifier is to improve the signal-to-noise ratio and at the same time provide high gain. This is accomplished by the use of two grounded-grid amplifiers and three high-gain amplifiers. The 60-MHz IF signal from the signal mixer is applied to the preamplifier. The first two stages are grounded-grid amplifiers using heavy loading which, although sacrificing gain, improves the signal-to-noise ratio of the signal. The circuits are fixed-tuned to a center frequency of 60 ±1.5 MHz.

A block diagram of the IF preamplifier and IF amplifier are shown in figure 3-10. You should refer to this diagram throughout this discussion. It permits you to readily visualize what we are discussing in the text.

The remaining three amplifiers are all high-gain amplifiers tuned to a center frequency of 60 ±1.5 MHz with an overall bandpass of 10 MHz. Gain is controlled by the application of a gain control voltage, which may be either manual gain control (MGC) or automatic gain control (AGC). This voltage is applied as a bias to the control grid of the final amplifier. If using MGC, a variable voltage of between 0 and approximately -10 volts can be applied from the center-tap of a potentiometer. When using AGC, the bias voltage is produced by video modulation, with the voltage varying inversely with respect to the amplitude of the video signal. The type of gain control which you may use is determined by the setting of a three-position switch. These switch positions are identified as MGC–AGC–NORM on the switch plate.

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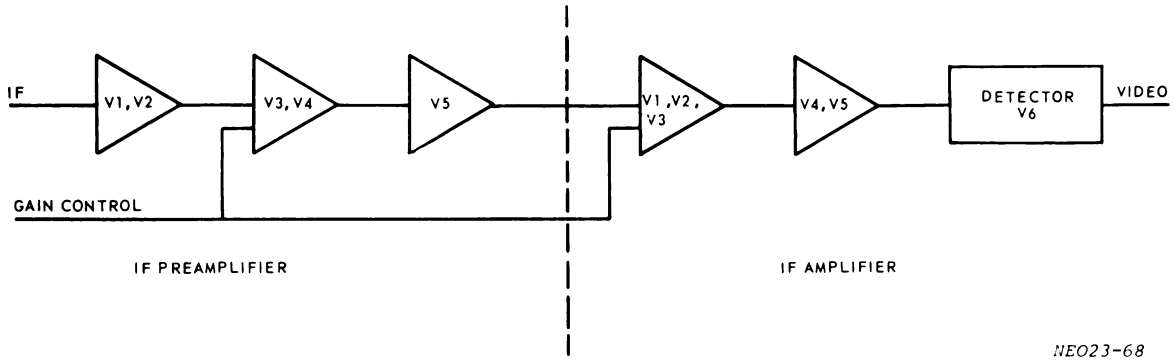

Figure 3-10. IF block diagram.

In the MGC setting, the amount of gain voltage applied is determined by the setting of a gain control potentiometer; and in the AGC position, from the modulated video. When in the NORM position, either the MGC or AGC voltage is used, depending on the tracking conditions of the radar. If all tracking conditions (azimuth, elevation, and range) are in full automatic, AGC voltage is used. If any one of the tracking conditions is in any mode other than automatic, MGC voltage is used.

IF Amplifier. The purpose of the IF amplifier is to further amplify the IF signal from the IF preamplifier and detect the video. The same gain control voltage and operating conditions that existed in the high-gain amplifier of the IF preamplifier apply to the first three IF amplifier stages.

The IF amplifier consists of five amplifier stages and a detector. The first IF amplifier stage can be capacitively tuned to obtain a flat frequency response between 50 and 70 MHz. The remaining four amplifier stages are fixed-tuned to 60 MHz ±1.5 MHz. Each amplifier is resistance-loaded to obtain a 10-MHz bandwidth. The final IF amplifier stage, a diode detector, detects during the negative portion of the IF signal. The resulting negative video pulses are either sent directly to the video amplifier or through a fast-time constant (FTC) circuit and then to the video amplifier.

Exercises (451):

1. What is the purpose of the IF preamplifier?

2. What is the purpose of the IF amplifier?

3. Which circuits of the IF preamplifiers are primarily responsible for increasing the signal-to-noise ratio?

4. Gain control voltage is applied to which stages in the IF amplifier and IF preamplifier?

5. What types of gain control are utilized in the IF preamplifier and IF amplifier?

452. List the types of interference reduction circuitry and state the effect each has on receiver operation.

Interference Reduction Circuits. We use two interference reduction circuits in most autotrack radars. Interference may be caused by nature, terrain, or weather. It may be accidental interference from nearby equipment or it can be intentional for jamming. Each type of interference reduces the possibility of receiving desired target returns. When the reception is reduced or obscured, the radar's efficiency is seriously hindered.

To reduce the effects of the aforementioned types of interference, the individual interference reduction circuits are used singly or together. The relation of these circuits to the normal receiver circuits is shown on the block diagram, figure 3-11.

The interference reduction circuits are FTC (fast-time constant) and STC (sensitivity time constant).

Fast-time constant (FTC). The purpose of the FTC circuit is to reduce the effect of large blocks of clutter or jamming signals. It is also used to increase the range resolution of targets at all ranges. This circuit is normally placed between the detector and the video amplifier. It consists of a differentiating circuit which is inserted into the receiver with a switch. This switch is accessible to the operator and enables him to utilize the FTC circuit when large intensified spots—the results of large blocks of clutter or jamming signals—appear on the indicators and obscure desired targets.

The negative video pulse output of the IF amplifier is differentiated and the positive portion of the differentiated pulse is shorted to ground by a diode. In

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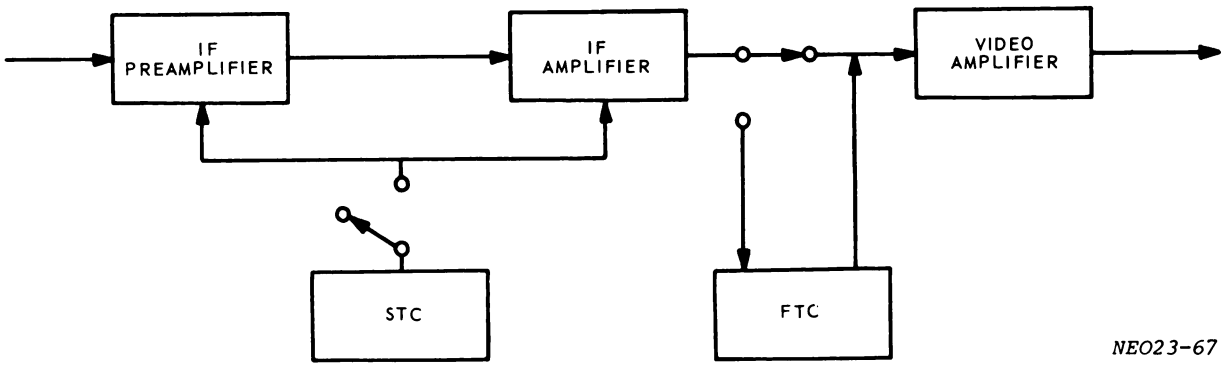

Figure 3-11. Interference reduction circuits.

this way, the relatively wide video pulse is changed to a sharp, narrow, negative video pulse. This results in reduction of the size of the returns on the indicators. The conversion of these video pulses not only aids the operator in distinguishing various returns in cluttered areas but also aids in reducing the effect of jamming.

Sensitivity time constant (STC). The purpose of the STC circuitry is to provide a means of reducing the effects of ground clutter. As you know, the closer a target or object is to the radar, the stronger the return. As the range of the target or object increases, signal (echo) strength decreases. STC does not increase the amplification for long-range target echos. Rather, STC reduces the receiver gain for short-range reception and gradually returns the receiver gain to its normal level as range increases. The STC is normally variable in duration and usually effective from zero to approximately 50 Kyds.

Figure 3-12 is a block diagram of a STC circuit. The trigger input is synchronized with the trigger initiating indicator sweeps and transmitter firing. The positive output of the multivibrator, the width of which can be varied by adjusting the WIDTH control, is applied to an RC circuit through a cathode follower. The RC circuit causes the trailing edge of the pulse to decay exponentially. The decay time is also made variable with the decay time control. At this point, we have a pulse containing a flat top with an exponentially decaying trailing edge. Both the width of the flat portion and the decay time of the trailing edge are variable. This pulse is sent to a clipper inverter through a cathode follower. The clipper inverter is biased below cutoff in order to limit the maximum duration of the trailing edge decay time. Limiting is possible because the stage will only be conducting for a portion of the applied pulse. The output of the STC is a negative pulse with an exponentially rising trailing edge. The width control determines how long the receiver is kept limited. The decay time control determines the length of time it will be after transmitter firing for a signal to receive full operating gain. The degree of gain limiting is determined by the setting of the STC control, which regulates the output amplitude of the negative pulse. Overall receiver gain when operating with STC is established by the setting of the GAIN control, which sets the negative DC level of the STC waveform.

Exercises (452):

1. What are the types of interference reduction circuits normally used with autotrack radars?

2. Which interference reduction circuits are effective at all ranges?

3. How is the degree of gain limiting determined when using STC?

453. State the purpose of the video amplifier and identify the input and output signals.

Video Amplifier. A video amplifier used in one of our systems is shown in figure 3-13. The purpose of any video amplifier is to amplify and improve the shape of the pulse received from the IF amplifier. (Remember, the IF output can also be routed through an FTC circuit before it arrives at the video amplifier.) As shown, two outputs are derived from the amplifier: nondelayed video and delayed video. The video outputs are used in the angle and range error channels for automatic tracking and for visual indicator displays.

After being amplified, the video is sent directly to the range error channel and to a 0.44-μsec delay network. The delayed video is also sent to the range error channel and to a mixer stage before being applied to the indicators. In the following AGC discussion, only the range error channel outputs affecting AGC operation are mentioned. The operation of the range error channel is discussed in Chapter 4 of this volume.

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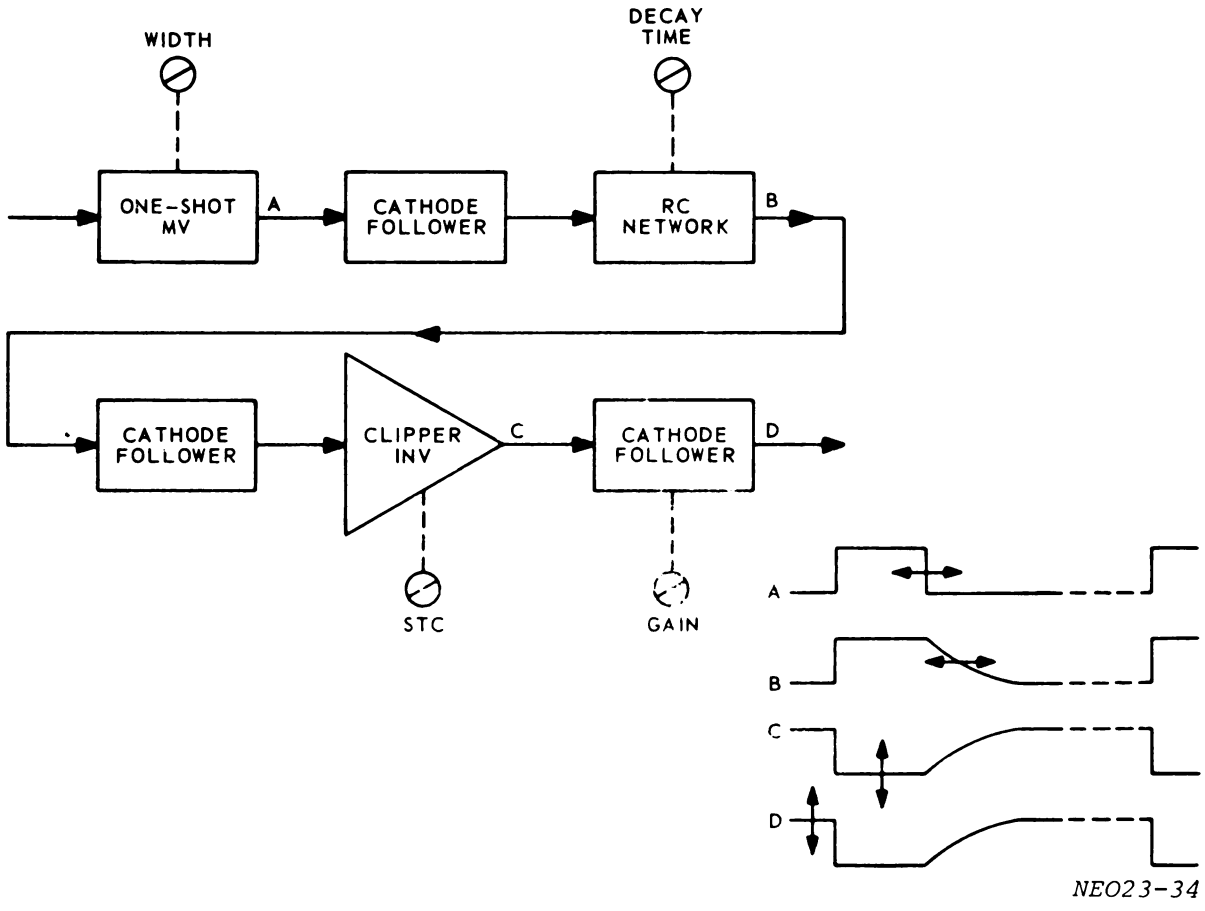

Figure 3-12. STC circuit.

Exercises (453):

1. What is the purpose of the video amplifier?

2. The two outputs of the video amplifier are sent to the range and angle error channels and indicator channel. What are these outputs called?

3. What is the input to the video amplifier and where does it normally come from?

454. List the two channels of the AGC unit and describe the effect each has on the operation of the receiving system.

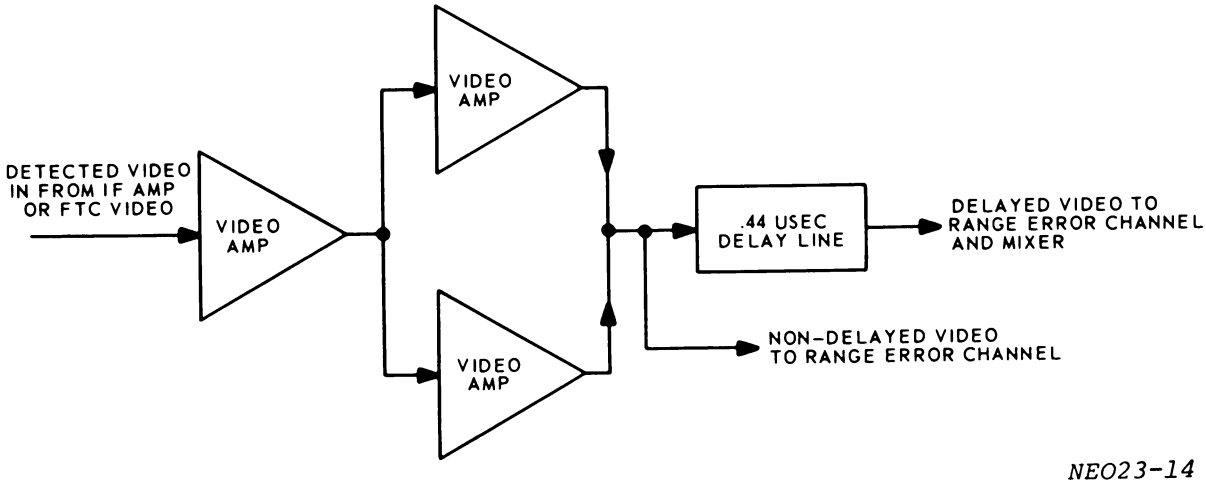
DETECTED VIDEO IN FROM IF AMP OR FTC VIDEO
VIDEO AMP
VIDEO AMP
VIDEO AMP
.44 USEC DELAY LINE
DELAYED VIDEO TO RANGE ERROR CHANNEL AND MIXER
NON-DELAYED VIDEO TO RANGE ERROR CHANNEL
NEO23-14

Figure 3-13. Video amplifier.

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Automatic Gain Control (AGC). In most autotrack radar systems, the AGC has two functions: to automatically control the gain of the IF and to supply the antenna positioning system with a 30-Hz error signal. In one autotrack radar, the 30-Hz error signal for the antenna system is supplied by a lobing error channel which also furnishes the AGC channel with an average DC voltage resulting from the 30-Hz error signal. Whether we separate or combine these two functions, the operating principle is the same. Since it is the intent of this course to be current on as much of the autotrack equipment as possible, we have combined the lobing error and AGC channel functions under the common heading of AGC.

Lobing error channel. This channel, shown in figure 3-14, furnishes a 30-Hz error signal to the angle detectors (both azimuth and elevation) in the antenna positioning system. It also develops a DC voltage proportional to the amplitude of the 30-Hz error signal and sends it to the AGC channel.

There are three inputs to the lobing error channel, the names and functions of which are as follows:

(1) Nondelayed video—Shifts the video baseline in order to prevent spurious ground clutter signals from distorting the error signal derived from the target being tracked.

(2) Gated video—Insures that the error signal is derived only from the target being tracked in range.

(3) Clear-out pulse—Returns the charge of the lobing capacitor to a voltage reference level at the end of each trigger interval.

To understand the development of the antenna error signal, we must start with the initial charge of lobing capacitor C24. With no other inputs, the clear-out pulse is applied to lobing capacitor charger V15. (Remember, the clear-out pulse is at the radar PRF.) The application of the clear-out pulse causes V15 to conduct and C24 to charge to approximately +20 volts. The amount C24 charges is limited by the diode associated with V15. Now let's apply the gated video to V13. The cathode of V13 is connected to two coincidence tubes not shown in the lobing error channel. These coincidence stages conduct whenever the range gate and video are applied at the same time. Conduction of these two stages regulates the conduction of V13; as conduction in the coincidence stage decreases, conduction in V13 increases. As V13 increases in conduction, a negative voltage is coupled to the cathode of lobing capacitor discharger V14. This causes V14 to conduct more and C24 to discharge an amount proportional to the amplitude of the gated video applied to V13. If the antenna is misaimed, the amplitude of the signals felt at V13 varies at a 30-Hz rate; therefore, the charge of C24 varies at the same 30-Hz rate. This varying charge of C24 is applied to cathode follower V16. This is done to make the voltage suitable for the AGC action at the IF amplifiers. The output of the cathode follower is also applied to the AGC channel which provides a balanced input to the azimuth and elevation angle detectors.

Any variation in the magnitude of the error signal impairs the accuracy of angle tracking. The greatest

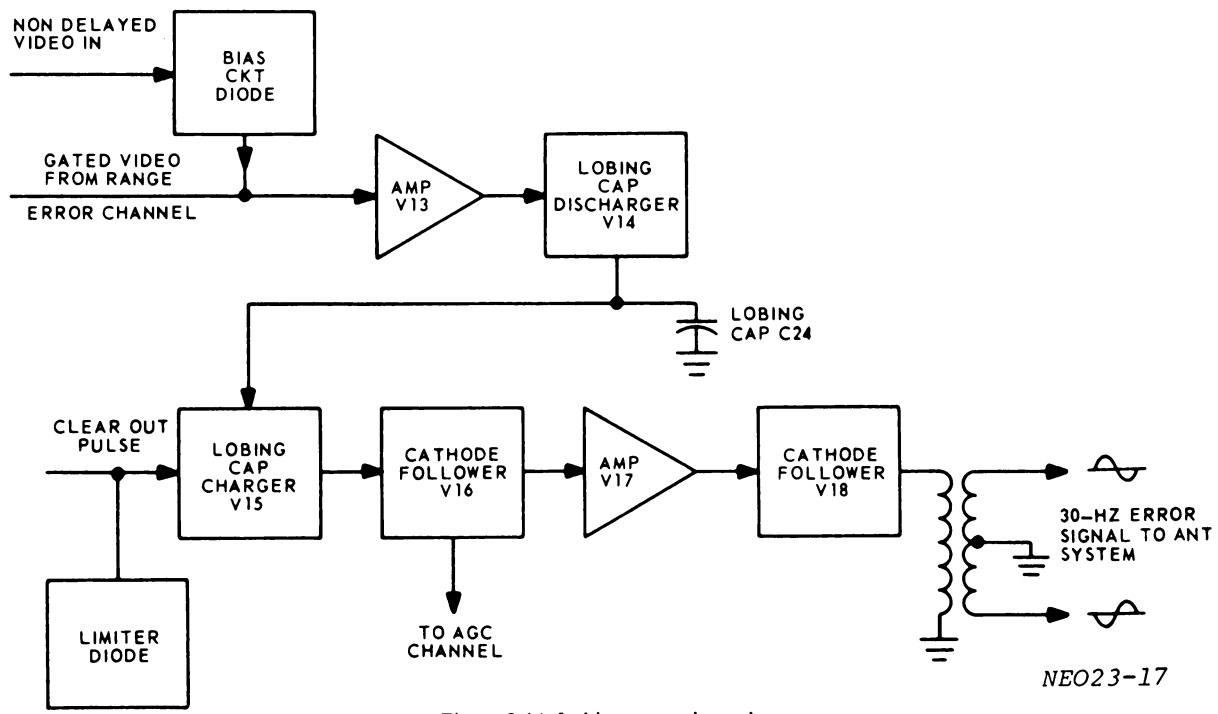

Figure 3-14. Lobing error channel.

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source of variation we find is due to ground returns when we are tracking a target at low elevation angles. Ground clutter, when mixed with the true target signal, shifts the baseline of the video signals to a positive value. This reduces the amplitude of the negative video signals and, since the baseline shift is at a 30-Hz rate (the nutating or scanning frequency), the phase of the true error signal is also shifted. This effect is eliminated by the bias circuit.

AGC channel. This channel is shown in figure 3-15. The output of the AGC channel is used to automatically control the gain of the IF preamplifier and IF amplifier. Normally, AGC is used only when the track radar is in automatic operation.

The input control voltage is supplied by a potentiometer. This voltage sets the DC level of the AGC channel.

The control voltage and 30-Hz error voltage are combined and added at the input of the low-pass filter. In this way, the control voltage aids the error voltage in performing its subsequent AGC function.

The filter is used to filter out the 30-Hz component of the error voltage. The filtered DC, which is varying inversely with the variations in video amplitude, is applied to the control grid of DC amplifier V17A.

DC amplifiers V17A and V17B have a common cathode resistor. V17B controls the gain of V17A. With no input, the cathodes of V17A and V17B are at a relatively high positive potential, causing V17B to be cut off. When an input lowers the grid potential of V17A, the plate voltage increases until the grid potential of V17B rises to a point at which it overcomes the cathode bias. When V17B conducts, the cathode potential of the tubes also increases, causing the plate voltage of V17A to go even more positive. The point at which V17B overcomes the cathode bias is called the "threshold." From this, you can see that AGC action is delayed until weak signals increase in strength to the threshold point. From this point on, almost complete compensation is obtained for video variations resulting from fading, distance, or other factors causing slow signal changes. The threshold point is determined by the setting of the AGC 2 control.

Clamper V10 prevents the output of V17A from going more positive than 0 volts.

The output of V17A is applied to V18A. DC amplifiers V18A and V18B operate similarly to V17A and V17B. AGC 1 control establishes the bias of V18B (the threshold point). Strong video signals cause the output of V18A to become more negative, thereby reducing the gain of the IF preamplifier and IF amplifier. Weak signals have the opposite effect.

Exercises (454):

1. What two channels comprise the AGC unit?

2. What is the dual purpose of the AGC unit?

3. What are the inputs to the lobing error channel?

4. Normally, AGC is used only when the track radar is in what kind of operation?

5. AGC action does not take place until weak signals increase to what point?

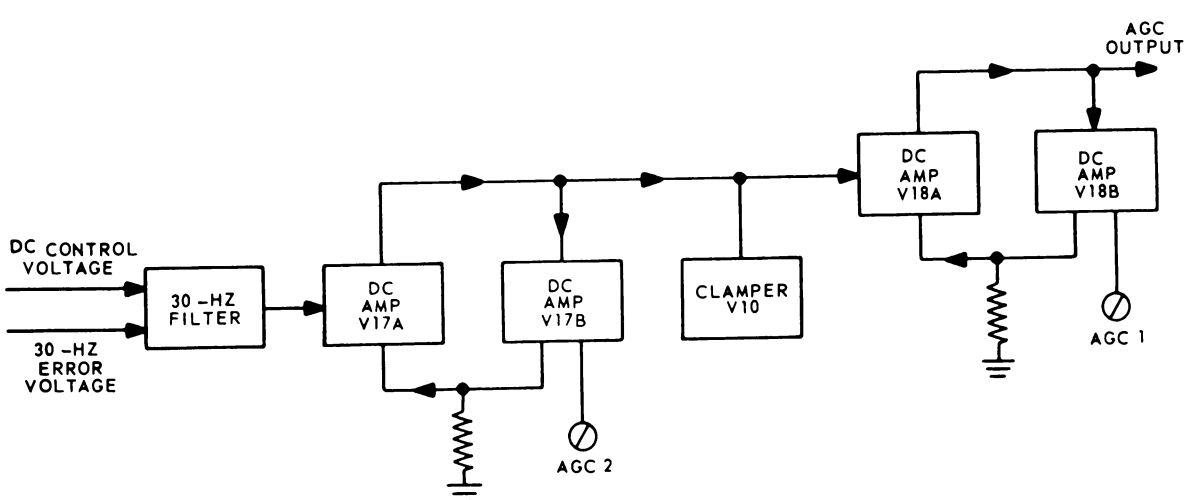

Figure 3-15. AGC channel.

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3-3. Beacon Operation

During beacon operation, the radar automatically tracks the response of an aircraft transmitter rather than the normal radar echo. This, of course, means different operating frequencies for the transmitter and receiver from those used with normal radar operation. Also, because the receiver is tuned to the aircraft transmitter instead of the track radar transmitter, a different method of AFC is required. Beacon operation also contains an inherent operational delay which can affect range accuracy. This delay occurs because the aircraft beacon must first receive and detect our transmitter pulse and then convert this pulse into a suitable trigger to fire the beacon transmitter. Referring to figure 3-16, you can see that the stages we are mainly concerned with for beacon operation are the local oscillator control, beacon local oscillator, beacon delay channel, and beacon AFC.

455. Provided a list of units required for beacon operation, match each with the purpose it accomplishes and state the effect each unit has on beacon operation.

Local Oscillator Control. In order that we may be able to switch from radar operation to beacon operation with no delay (due to the different operating frequencies), two local oscillators are used. This eliminates the need of tuning a single local oscillator to our transmitter for normal radar operation and then returning it to the beacon transmitter frequency for beacon operation. The proper local oscillator is selected by use of a switch, two solenoids, and two waveguide shutters.

The switching arrangement allows the outputs of either the radar local oscillator or the beacon local oscillator, *or both,* to be used at any one time. The switch is labeled RADAR, BEACON, and BOTH. Electrically, the switch is connected to a DC voltage which, when applied to the solenoids, causes an associated shutter to be removed from the waveguide. Both local oscillators are used when operating in the beacon mode and when it becomes necessary to calibrate range data for an unknown beacon signal delay. In this way, both the normal radar echo and the beacon pulse can be viewed simultaneously on the radar indicator to determine the beacon range error.

Beacon Local Oscillator. Except for tuning, the beacon local oscillator operates the same as the radar local oscillator previously discussed. The beacon local oscillator is tuned to a frequency 60 MHz below that of the beacon transmitter if the beacon transmitter frequency is lower than that of the radar transmitter. If the beacon transmitter frequency is higher than that of the radar transmitter, the beacon local oscillator is tuned 60 MHz above the beacon transmitter frequency.

Beacon Delay Channel. Refer to figure 3-2 to see where the beacon delay channel fits into the autotrack

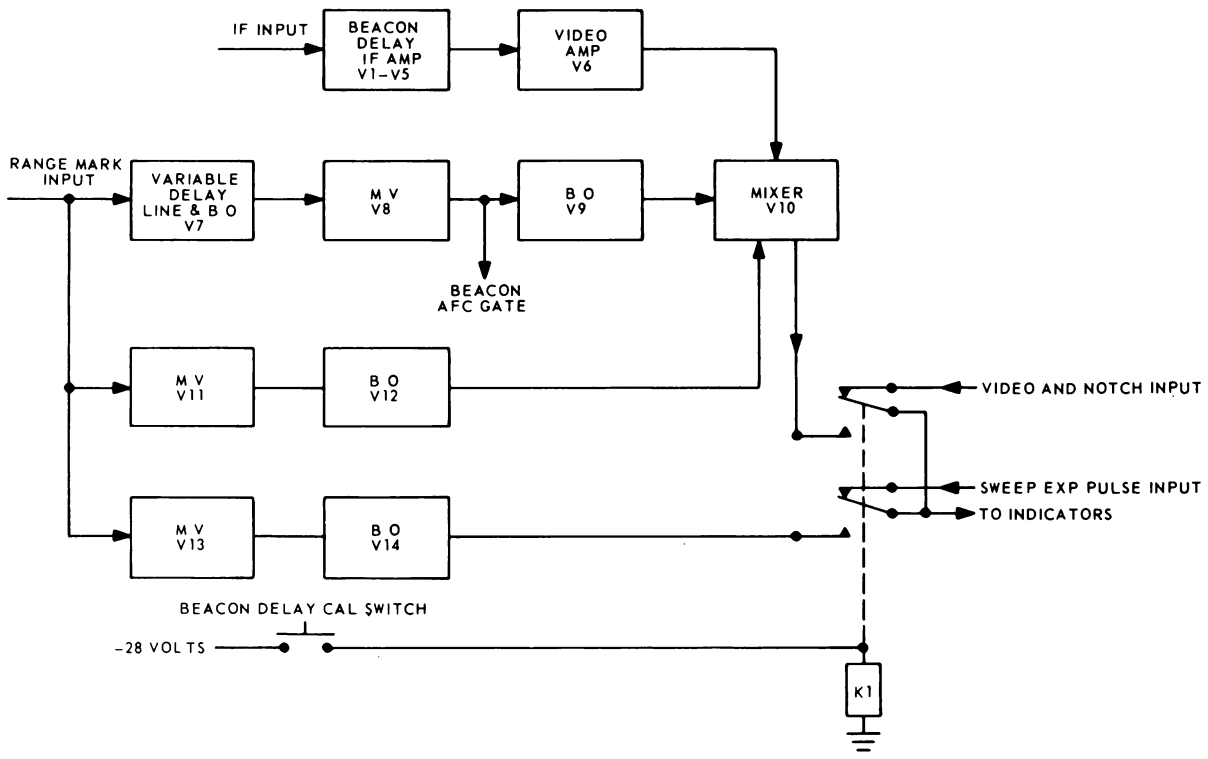

Figure 3-16. Beacon delay channel.

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radar, then refer to figure 3-16 for the following discussion. The beacon delay channel is used to determine and compensate for the beacon delay when the delay is unknown. If the delay is known, a variable delay line is adjusted to compensate for it.

The IF from the IF preamplifier (from beacon, radar, or both) is sent to the beacon delay IF amplifier. Operation of the beacon delay IF amplifiers is similar to that of the IF amplifier, except that instead of using AGC to control the amplifier gain, you must manually adjust the gain.

The BEACON DELAY CAL switch functions to display the actual delay. Tracking range marks from the range system are applied to a variable delay line and two multivibrators. One multivibrator (V13) and its associated blocking oscillator (V14) generate a pulse which is used to expand a portion of the indicator sweep during calibration. The other multivibrator (V11) and its associated blocking oscillator (V12) generate a pulse, approximately 100 yards wide, which is applied to mixer V10. The delayed track range mark from the variable delay is sent to multivibrator V8. This multivibrator develops another 100-yard-wide pulse which is sent to blocking oscillator V9. (This same pulse is also used to gate the beacon AFC circuit.) The output of the blocking oscillator is sent to the mixer. At this time, then, there are three inputs to the mixer: the radar 100-yard gate, the beacon 100-yard gate, and the beacon video. (Remember, this could be both radar and beacon video.)

Depressing and holding the BEACON DELAY CAL switch energizes relay K1. This disconnects the normal radar gate inputs going to the indicators and connects the gate outputs of mixer V10 and blocking oscillator V14. The display now consists of radar *and* beacon video, and radar *and* beacon 100-yard gates. If all video and gates are not properly centered, the delay must be adjusted until they are correct. Once they are properly centered, there will be no range error when switching from radar operation to beacon operation.

Beacon AFC. The purpose of the beacon AFC is to automatically maintain the beacon local oscillator frequency 60 MHz away from the aircraft beacon transmitter frequency. In order to control the beacon local oscillator with the beacon response, a beacon AFC gate (resulting from the beacon video) is applied to the AFC network. Figure 3-17 is a block diagram of the AFC network. Two inputs are applied to the network: the AFC gate and the IF signal from the IF amplifier. The IF input is fed to three amplifier stages, all tuned to 60 MHz, and applied to a frequency discriminator. The discriminator produces a negative voltage signal if the IF input is below 60 MHz. When the IF input is exactly 60 MHz, no voltage signal is developed.

The output of the discriminator is applied through a cathode follower to a video amplifier where the signal is amplified and inverted. From the video amplifier, the signal is applied to a gating circuit (pulse stretcher) through another cathode follower.

The beacon AFC gate is inverted and also sent through a cathode follower to the same pulse stretcher, a dual-diode-type tube. The diode and its associated circuitry stretch the gate into a comparatively steady DC control voltage. With no discriminator input, equal currents flow through both diode sections. This causes two capacitors, one in each diode circuit, to have equal and opposite charges. At the instant the beacon AFC gate is no longer felt at the input, each capacitor biases its diode at cutoff. The diodes remain cut off during the AFC gate pulse interval.

When a discriminator output is applied to the diode circuit, its voltage is algebraically added to the capacitor voltages. If the discriminator output is negative, positive voltage is applied to the diode circuit, causing

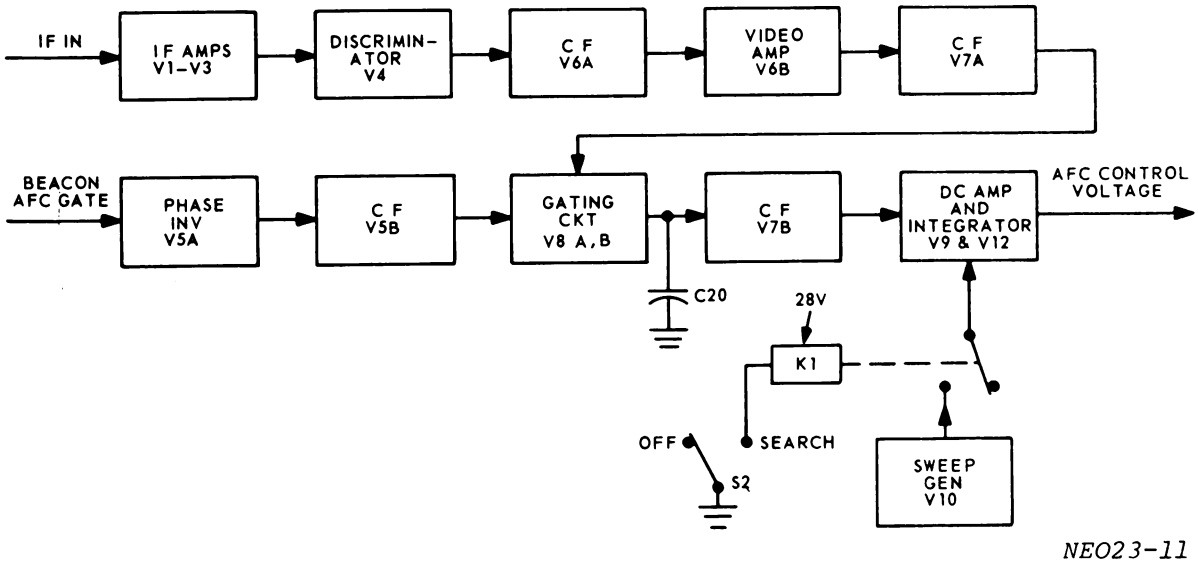

Figure 3-17. AFC network.

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an imbalance of the capacitor charges. This causes current to flow through V8B and causes capacitor C20 to assume a positive charge. At the end of the pulse, the charge on C20 is applied to cathode follower V7B as a control voltage. If the discriminator output is positive, V8A conducts and the charge on C20 is negative. When the next AFC gate is applied to the circuit, C20 discharges through one of the diodes, depending on its charge polarity, removing the control voltage from V7B.

The control voltage is sent through V7B to V9 and V12. With AFC search switch S2 in the OFF position, V9 and V12 function as an integrating amplifier. In the SEARCH position of the switch, V9 and V12 function as DC amplifiers. As you recall, an integrating amplifier changes a rectangular pulse into a triangular pulse (sawtooth). This sawtooth output is sent to the repeller plate of the local oscillator with the necessary polarity to change the local oscillator frequency in the direction required to obtain a 60-MHz IF.

In the SEARCH position of S2, the output of the AFC circuit is derived from sweep generator V10, a free-running phantastron similar to that discussed with the searching mode of the radar AFC. The output of V10, after being amplified by V9 and V12, causes the local oscillator to sweep over the operating portion of the frequency spectrum. Unlike the radar AFC search mode, there is not automatic frequency lock-on once a correct IF is obtained. The result must be visually observed and manually established.

Exercises (455):

1. Match the terms in column A with the appropriate purposes in column B by writing the correct letter in the blank provided. Purposes may be used only once or not at all.

Column A	*Column B*
_____ 1. Local oscillator control.	a. Maintains the beacon local oscillator ±60 MHz away from the aircraft transponder frequency.
_____ 2. Beacon local oscillator.	b. Enables switching between RADAR and BEACON operation with no delay.
_____ 3. Beacon delay channel.	c. Determines and compensates for transponder delay.
_____ 4. Beacon AFC.	d. Provides a continuous-wave signal to the mixer during beacon operation.
	e. Maintains the radar local oscillator ±60 MHz away from the aircraft transponder frequency.

2. How is the gain of the beacon delay channel controlled?

3. In beacon operation, what do you adjust until the radar and beacon video are centered on the radar and beacon 100-yard gates?

4. Beacon delay calibrate and beacon gating are necessary to compensate for the inherent delay in beacon operation. What causes this delay?

3-4. Performance Measurements

Radar receiver performance is determined by many factors, most of which are established in the original design. In this section, only those factors concerning maintenance are considered. The most important factors are: (1) receiver sensitivity, (2) TR recovery, and (3) receiver bandwidth. Each of these will be covered separately.

456. Define receiver sensitivity and identify the controlling factors of two methods of determining the sensitivity of an autotrack receiver.

Receiver Sensitivity. Radar receiver faults are the most common causes of loss of maximum range performance. This fact is mainly due to the greater number of adjustments and components associated with the receiver. Loss of receiver sensitivity has the same effect on range as a decrease in transmitter power. For example, a 6-dB loss of receiver sensitivity would shorten the effective range of a radar just as much as a 6-dB decrease in transmitter power. Such a drop in transmitter power is very evident in meter indications and, therefore, is easy to detect. On the other hand, a loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is very difficult to detect unless accurate measurements are made.

Receiver sensitivity is the ability of the receiver to pick up weak signals. The greater the sensitivity, the weaker the signal that can be picked up. Sensitivity is measured by determining the power level of the minimum discernible signal (MDS). MDS denotes the weakest signal that produces a visible output, and its value is determined by the receiver output noise level, which tends to obscure weak signals. For example, a noisy receiver will be less sensitive than a quiet one. It follows that an MDS measurement is dependent on the receiver noise level and that measuring either MDS or noise will give an indication of the receiver sensitivity.

Minimum discernible signal. A very high degree of attenuation (approximately 98 dB for the average receiver) is involved in the MDS measurement. A very

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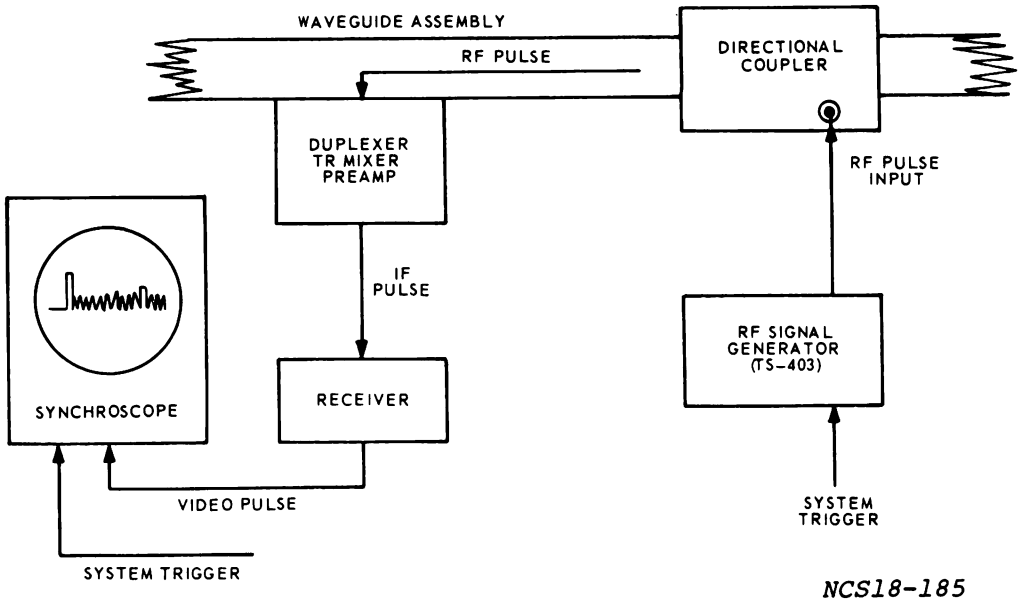

Figure 3-18. MDS measurement.

low-power level (about 1 micromicrowatt) is also involved. Because of these factors, very little RF leakage from the signal generator can be tolerated, or the amount of leakage signal picked up by the receiver will be appreciably compared to the signal fed through the attenuator. Since leakage signals are independent of the attenuator setting, very inaccurate MDS readings can be obtained when leakage is present. If the leakage signal is in phase with the signal through the attenuator when it reaches the receiver, the MDS reading will indicate a false high receiver sensitivity. A defective receiver could appear to be normal. The other extreme could happen if the leakage was out of phase with the signal through the attenuator. So it is important that the leakage in the RF system be kept to a minimum.

You can determine the leakage by taking a MDS reading with the signal generator at one location and then moving it to another location. If the readings differ, leakage is present at one of the two locations.

The following steps are used to check receiver MDS when using the signal generator setup, shown in figure 3-18.

(1) Connect the radar trigger to the signal generator.

(2) Connect the output of the signal generator to a waveguide assembly coupler.

(3) Tune the signal generator to the transmitter frequency while observing the A-scope.

(4) Adjust the reference level on the signal generator power meter (zero set).

(5) Adjust the receiver gain to just below saturation.

(6) Observe the artificial echo on the A-scope and if it coincides with a target, vary the delay control on the signal generator to move the echo away from the target.

(7) Tune the receiver for maximum echo.

(8) Increase the attenuation until the echo is just barely visible in the noise (see fig. 3-19). This is the MDS level.

(9) Find the total attenuation by adding the attenuator reading (dB), coupling loss (dB), and cable loss (dB). The value obtained will be expressed in -dBm.

Noise figure. The term "noise figure" (NF) is applied to a radar receiver to indicate how much noise is to be expected. It is defined as the ratio of measured noise to calculated noise, and may be expressed as a power ratio or in dB. A few radar systems contain noise circuits as internal equipment while others require external test equipment to check noise figure. We will limit our discussion to a system which utilizes internal circuitry.

Figure 3-20 is a simplified diagram of internal noise monitoring circuitry as utilized in automatic tracking radar systems. This circuitry will be discussed in the following paragraphs.

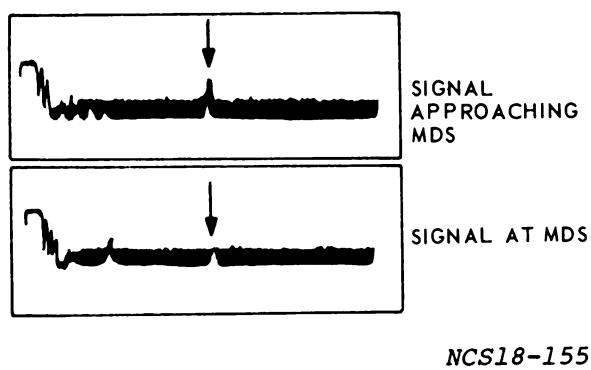

Figure 3-19. MDS signals.

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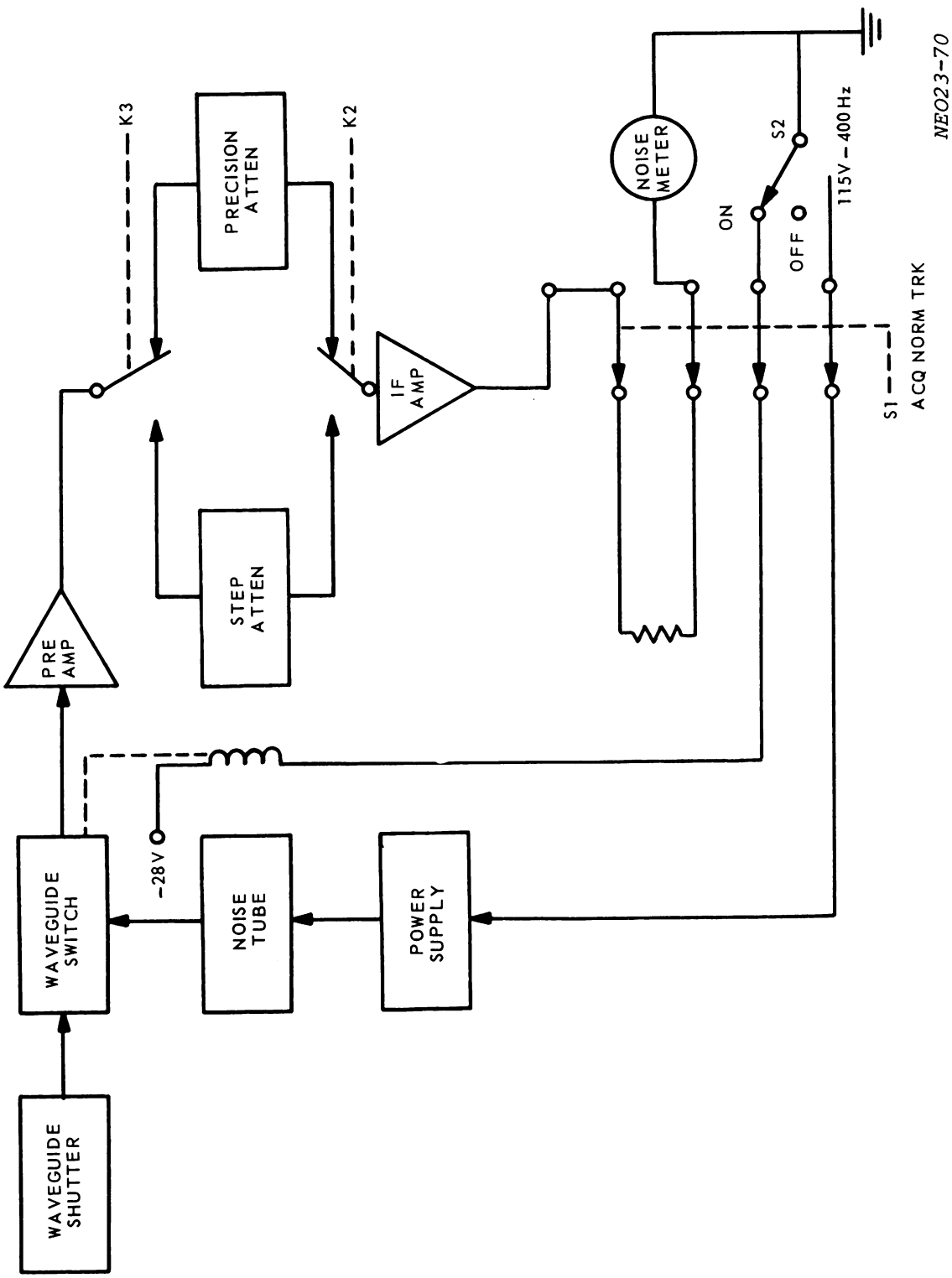

Figure 3-20. Noise figure, simplified diagram.

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The waveguide shutter, preceding the waveguide switch, is closed during noise figure measurements to prevent unwanted signals from entering the receiving group. This shutter is inserted into the waveguide when the shutter relay coil is deenergized. The coil has -28V applied to one side and ground applied to the other side through the shutter interlock relay and the TR tube ignitor current relay when the system is in OPERATE and transmitting. When taking noise figure measurements, the set is placed in READY condition. This removes the ground from the coil of the shutter relay resulting in the shutter being inserted into the waveguide.

Placing the ACQ-NORM-TRK switch in the TRK position applies ground to relays K2 and K3. This places the precision-variable attenuator in the IF line in place of the normal step attenuator. The I-band noise tube and noise tube power supply are also activated and allowed to warm up. The noise tube will immediately begin to generate an output. This output will not be used until the waveguide switch is activated placing it into the IF preamplifier. This allows the noise tube to stabilize while we proceed to set the reference levels from which our final readings are determined. The noise figure meter is also inserted into the receiver circuitry with the ACQ-NORM-TRK switch. It is placed across the output of the IF amplifier to measure the DC level of the detected IF noise.

After a reference level has been established on the noise figure meter, the NOISE ON-OFF switch (S2) is placed in the ON position. This activates the waveguide switch coil through the NOISE ON-OFF switch and the ACQ-NORM-TRK switch. With the coil energized, calibrated noise power is injected into the receiver. This calibrated noise power will increase the noise figure meter to some value greater than the previously set reference level. The attenuator setting of the precision variable attenuator is now increased until the meter indication returns to that of the original reference setting. The amount of attenutation, in dB, necessary to accomplish this is the Y dB factor and is read directly from the dB dial on the receiver monitor control panel.

The receiver noise figure is obtained by taking the dB reading determined above and entering the chart shown in figure 3-21 under Y dB. Reading to the left under NF (dB) will give you the noise figure at that moment. This figure can then be converted directly to an MDS (minimum discernible signal) reading by the graph shown in the same figure. Enter the graph at the bottom with the NF (dB) and read to the left the direct conversion. Noise figure or MDS readings do not have much significance when taken separately. It is only when they have been taken over a period of time and plotted that they do have significant meaning. They will show any trends in degradation of receiver sensitivity and can be used to predict possible failure of the receiver before it happens.

Exercises (456):

1. Name the two methods of determining receiver sensitivity.

2. Define receiver sensitivity.

3. What test equipment is required for determining receiver sensitivity by each of the methods?

4. How can you insure that leakage does not affect your readings when taking MDS measurements?

5. In what condition must the radar be when noise figure checks are being made?

6. Minimum discernible signal is most often expressed in what term?

7. What should the noise generator output be adjusted to when checking the noise figure of a receiver?

NF (DB)	Y (DB)
3	15.15
4	15.2
5	13.2
6	12.2
7	11.35
8	10.4
9	9.5
10	8.6
11	7.8
12	6.95
13	6.18
14	5.4
15	4.75

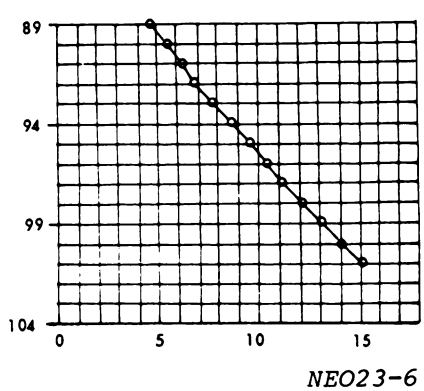

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Figure 3-21. Noise figure charts.

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457. Define TR recovery time and state what is necessary to measure it.

TR Recovery Time. TR recovery time is determined by the time it takes the TR switch to deionize after each transmitter pulse. It is usually defined as the time required for the receiver sensitivity to return to within 6 dB of normal after the end of the transmitter pulse. TR recovery time is the factor that limits the minimum range of a radar because the radar receiver is unable to receive signals until the TR switch is deionized. In various radar sets, the recovery time may vary from about 3 to 20 microseconds.

Recovery time can be measured by using either a pulsed signal generator or a CW signal generator. We will discuss the pulsed signal generator method first.

When performing TR recovery time measurements utilizing the pulsed signal generator method, the following steps apply:

(1) Use the same test setup as for an MDS measurement (refer to fig. 3-18).

(2) Set the receiver gain to give about 1/8" noise on the A-scope.

(3) Adjust the calibrated attenuator to give a pulse amplitude about halfway between the noise level and saturation. Note the attenuator reading.

(4) Reduce the attenuator setting by 6 dB.

(5) Turn the phase control (time-delay control) to position the pulse closer to the transmitter pulse. Continue turning the control until the pulse amplitude drops to the level established in Step (3).

(6) Read the range at which the pulse is now located. The value obtained is the recovery time within 6 dB of normal receiver sensitivity. (Recovery time may be indicated in either microseconds, miles, or yards so long as subsequent readings are in the same units.)

Measurement of TR recovery time utilizing a CW signal generator is also possible. The procedure is as follows:

(1) Connect the signal generator to the coupling device.

(2) Adjust the radar receiver gain to give about 1/4" of noise on the A-scope.

(3) Tune the signal generator to the radar receiver frequency. Proper tuning will be evidenced by a rise in the trace on the A-scope.

(4) Adjust the output of the signal generator (calibrated attenuator) to a point just below receiver saturation. The indication on the A-scope should be similar to figure 3-22.

(5) Measure the range between the transmitter pulse and the point on the A-scope where the noise amplitude is one-half the maximum noise level.

Exercises (457):

1. Define TR recovery time.

2. What test equipment is required to perform each of the methods of checking TR recovery time?

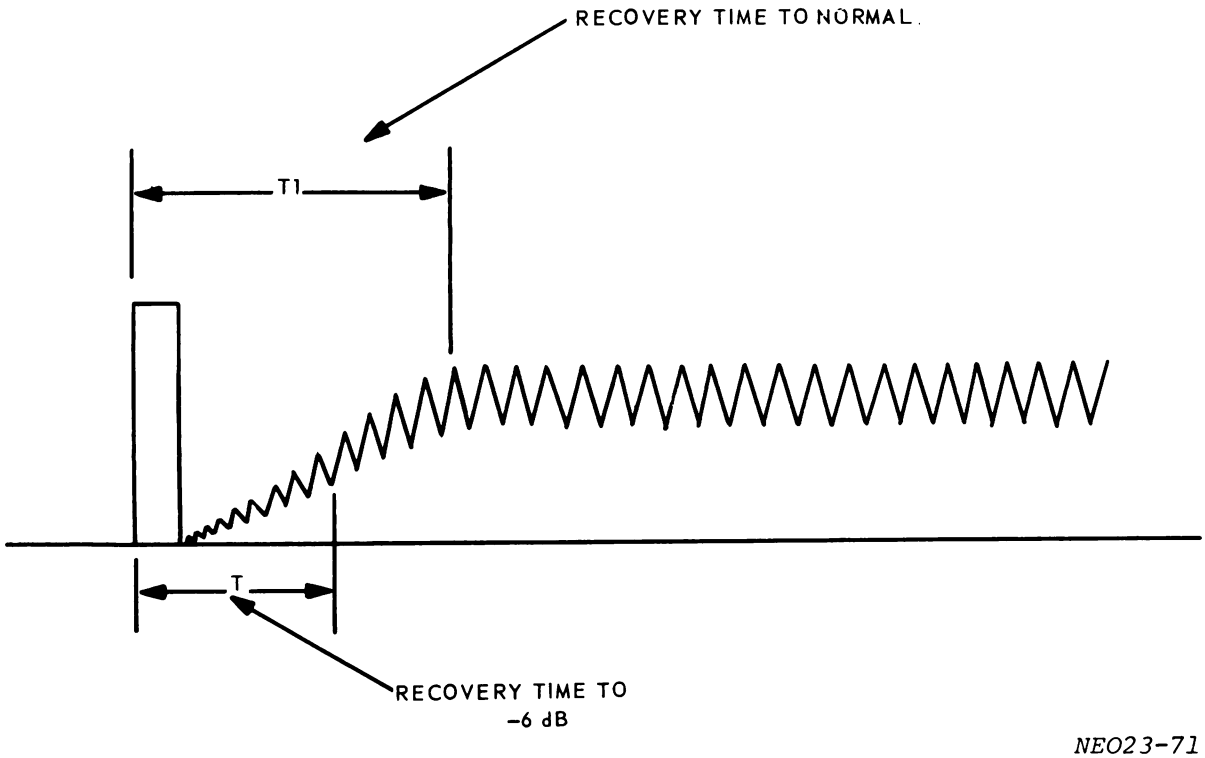

Figure 3-22. TR recovery indication using a CW signal.

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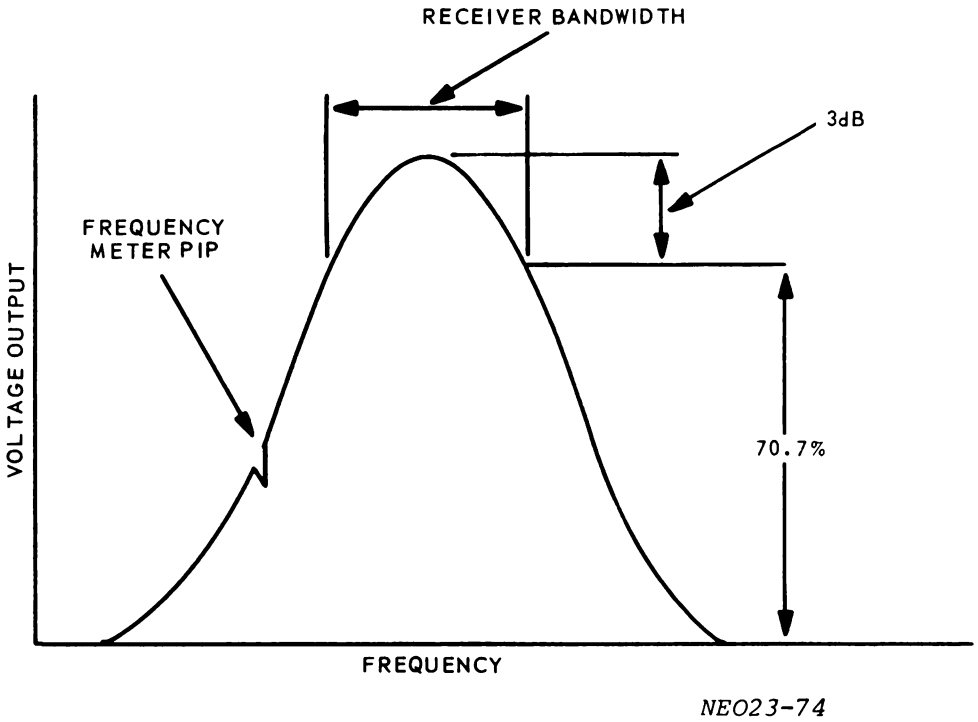

Figure 3-23. Receiver response curve. Synchronizer pulse relationship.

3. In what terms is TR recovery time usually stated?

458. Define receiver bandwidth and state the procedures for determining the bandwidth of a receiver.

Receiver Bandwidth. Receiver bandwidth is the frequency spread between the half-power points on the receiver response curve. Figure 3-23 shows a typical response curve. Since this curve is in terms of voltage, the half-power points are represented by the 70.7 percent voltage points.

A method of measuring bandwidth makes use of the MDS test setup using the FM signal generator. The measurement procedure is as follows:

(1) With the equipment connected in the same manner as for an MDS measurement, turn the signal-width control to obtain a response curve about one-half inch wide.

(2) Reduce the receiver gain to obtain a noise amplitude that is just barely visible.

(3) Adjust the calibrated attenuator to produce a pulse amplitude below receiver saturation level.

(4) Tune the frequency meter until the response curve shows an absorption pip at one of the half-power points. (See fig. 3-22.) Read the frequency, then repeat for the other half-power point. The difference between these two frequencies is the receiver bandwidth.

When the foregoing procedure is used, the half-points may be located very easily as follows:

(1) Note the attenuator dial reading following step (3) above.

(2) Increase the reading 3 dB and mark the level at the top of the response curve.

(3) Return the attenuator to the previous value.

(4) The half-power point is at the level marked in step (2).

Receiver bandwidth is specified for each radar, but wide variations are tolerated. If either the bandwidth or the shape of the receiver response curve is not correct, it is well to remember that a considerable change in circuit components is required to materially alter the response. In addition, radar range performance is not appreciably affected until quite a large change in response occurs.

Exercises (458):

1. Define receiver bandwidth.

2. What test equipment is necessary when checking the bandwidth of a receiver?

3. How much is the attenuator dial reading changed in order to determine the upper and lower frequency limits of the receiver?

4. What effect will a small change in the response curve of the radar receiver have on overall performance?

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Range Systems

IN THIS CHAPTER, you will study the principles of system synchronization and range tracking. A thorough knowledge of these principles will help you maintain, troubleshoot, and repair autotrack range systems.

4-1. System Synchronization

Since many radar functions depend on proper timing, the synchronizing system is one of the most important systems in autotrack radars. While some of the radars have relatively simple synchronizers, others are very complex. We will discuss a representative of each type.

459. State the function of selected items shown on a block diagram of a pulse synchronizer.

Pulse Synchronizer. The main function of a synchronizer system is to generate triggers and establish a time standard for the radar. This, in itself, is no great problem. Some of our radars employed a synchronizer that performs only this function. It is commonly referred to as a pulse synchronizer.

There are three timing pulses generated in this synchronizer. They are range preknock, preknock, and sync pulses. The range preknock is sent to the track range computer 11 to 69 microseconds before the transmitter fires. The preknock triggers the rest of the sweep and timing circuits 5 microseconds before radar transmission occurs; this allows sufficient time for the circuits to stabilize before the magnetron fires. The sync pulse triggers the transmitter and IFF/SIF circuits. (See fig. 4-1.)

Figure 4-2 shows the block diagram of this type of synchronizer. The mode of operation depends on the position of switch S1. When S1 is in the CAL position, accurately spaced pulses from the range calibrator are used to trigger the synchronizer. This position is only used for alignment purposes.

Placing S1 in the INT position permits the synchronizer to free-run at a frequency determined by blocking oscillator V2. The sync amplifier is not used when S1 is in this position. The output of V2 is a positive-going pulse 2 microseconds in duration and is called the range preknock pulse.

The output of V2 is also used to trigger the phantastron delay circuit V6. The output of V6 can be delayed 6 to 64 microseconds with respect to the range preknock pulse. The exact setting of this delay is determined during the alignment of the track range computer.

The output of V6 is used to trigger blocking oscillator V3. The output of V3 is applied to cathode followers V4 and V5. V4 produces the preknock pulse. The output of V5 is applied to network Z1 which has a delay of 5 microseconds. Thus, the sync pulse is delayed 5 microseconds with respect to the preknock pulse.

Exercises (459):
Refer to figure 4-2.

1. What is the function of V6?

2. What is the function of V2?

3. Why is Z1 used?

4. When is V1 used?

460. Given a block diagram and waveforms of a systems synchronizer, identify selected timing relationships.

Systems Synchronizer. Other radar systems in our career field use synchronizers that have some of the range determination and indicator unblanking circuitry incorporated in them. Foldout 1, in the back

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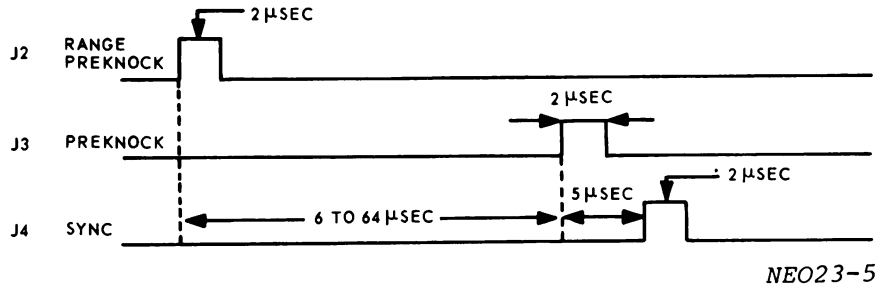

Figure 4-1. Synchronizer pulse relationships.

of this volume, is a block diagram of a systems synchronizer. The block diagram is divided into two parts: a reference chain and a phase chain.

Reference chain. The reference chain contains the master timer which generates the basic synchronizer frequency, divider stages which develop divisions of the basic frequency, sweep drive voltages, sweep unblanking gates, and a track gate. All of these voltages are time-fixed and are shown in foldout 1.

Operation of the synchronizer is initiated by the master timer. It is a crystal-controlled oscillator which generates a highly stable output.

The sine-wave output of the master timer is applied to the 200-yard indicator sweep transformer and a trigger tube and blocking oscillator (not shown in FO 1). The trigger tube is an overdriven cathode follower which converts the 82-kHz sine wave to an 82-kHz square wave. These square waves are applied to the blocking oscillator, which produces a train of 82-kHz positive-going pips that coincide with the leading edges of the input square waves. These pips are called the 82-kHz reference pulses and are the accuracy standard for the entire radar system.

The divider stages are used to count down the master-timer frequency from 82 kHz to 410 Hz. This not only establishes our basic PRF of 410 PPS but also supplies the various frequencies required for sweep drives, sweep unblanking gates, and phasing requirements for more accurate range determination.

The 82-kHz reference pulses are applied to the first frequency divider stage. The frequency divider consists of four free-running multi-vibrators. The output frequency of dividers one through four, in that order, is 16.4 kHz, 4.1 kHz, 820 Hz, and 410 Hz. The output of the second divider is applied to the following:

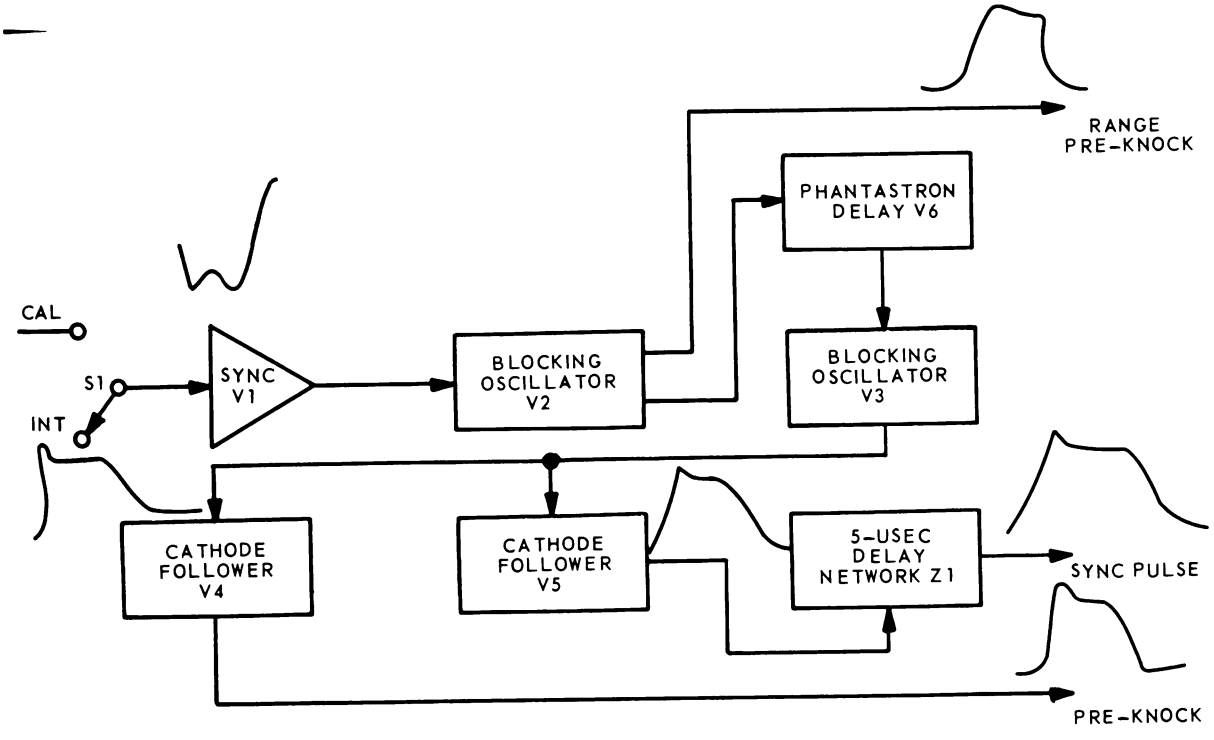

Figure 4-2. Synchronizer block diagram.

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- The 4.1-kHz selsyn in the range computer for time phasing.
- The range indicator for the 40,000-yard sweep drive.
- A gate multivibrator in order to establish a fixed delay and subsequently establish a time coincidence with a 410-Hz gate.
- The third divider as a synchronous input trigger.

The fourth divider receives a synchronous input from the third divider and provides outputs to the following:

- The 410-Hz selsyn in the range computer for time phasing.
- A gate multivibrator used to develop the 40K yard sweep unblanking gate and also to establish a time coincidence with the second divider output.

Now that we have seen what the divider stages do, let's see why. The 82-kHz oscillator frequency is used as a convenient means of accurately measuring range. This is because of one cycle being equivalent to 12.36 μsec, or 1 radar mile. Since we also use a range indicator to represent 2000 yards, the 82-kHz output is also used as the 2000-yard sweep drive voltage.

The 4.1-kHz output of the second divider is used because one of the range indicators represents the 40,000-yard range. Since the time of one cycle of the 4.1-kHz frequency is 244 μsec, the 4.1-kHz sweep drive output of the second divider satisfies this requirement.

The 410-Hz output of the fourth divider establishes the sweep time representing the 400,000-yard range.

In addition to satisfying the requirements for the range scopes used, the outputs of the divider stages also supply the selsyns in the range system with the required frequencies for subsequent gate and trigger phasing.

The gate multivibrators and coincidence stages are used to develop the range sweep unblanking gates. All of these gates occur with a definite time relation to each other, as shown on FO 1. These gates are indicated in the block diagram (FO 1) by a corresponding letter.

Two one-shot gate multivibrators receive inputs from the divider stages. The multivibrator receiving the output from the 410-Hz divider (FO 1, reference chain waveform C) is triggered by the trailing edge of the input pulse. Since the frequency of this pulse is 410 Hz, the trailing edge of the pulse occurs once every 2440 μsec. The output of the multivibrator (D of FO 1) is a pulse 220 μsec wide (approximately 38,000 yards). This pulse width is variable and is adjusted so that approximately 30,000 yards of the available 40,000 yard sweep drive is unblanked.

The gate multivibrator receiving its input from the 4.1-kHz divider (B of FO 1) is triggered by the trailing edge of the input pulse. Since the frequency of this input is 4.1 kHz, the trailing edge of the pulse occurs once every 244 μsec. The output of the multivibrator (E of FO 1) is a pulse 105 μsec wide (approximately 17,000 yards). This pulse width is variable and is adjusted so that the position of pip F in the figure can be exactly in the center of gate D. Gate E is differentiated and sent to a coincidence stage. Also applied to the coincidence stage is the 410-Hz 40,000 yard sweep unblanking gate (D or FO 1).

If a coincidence stage receives two gates of different frequencies, the gate width of the output is the same as the narrowest gate-width input at the lowest frequency input. The output of the coincidence stage is, therefore, a negative pip at a frequency of 410 Hz (F of FO 1). Remember, the time position of this pip is dependent on the width of gate E.

The negative pip output of the coincidence stage is applied to a one-shot multivibrator where a 10-μsec pulse is developed (G of FO 1). This 10-μsec pulse is the 2000-yard unblanking gate and occurs directly in the center of the 40,000-yard unblanking gate (waveform D of FO 1). The trailing edge of this gate is time-variable and is usually adjusted so that approximately 1500 yards of the available 2000-yard sweep drive is unblanked.

Up to this point, we have developed 40,000-yard and 2000-yard sweep unblanking gates. We now have a means of unblanking these two range scopes for the desired range within the maximum sweep drive range limitations. We have also time-positioned the 2000-yard unblanking gate so that it occurs exactly in the center of the 40,000-yard unblanking gate. We have, in effect, expanded the 2000-yard center portion of the 40,000-yard sweep. We do this in order to always locate the target being tracked in the center of the sweeps.

The track gate, often called the *range gate*, is the gate that determines the accuracy of the range measurement. Range is measured by the electrical distance between the position of the track gate and the trigger. Since in this case the track gate is referenced, its position always remains fixed. Also, since range tracking requires the target to be located exactly in the center of the 40,000-yard and 2000-yard range sweeps, we must have a means to keep the track gate always in the center of the sweep unblanking gates.

The output of the 2000-yard unblanking gate multivibrator is applied to a coincidence stage along with 82-kHz pips. These pips occur every 12.2 μsec, and it is therefore impossible for more than one pip to occur within one 10-μsec gate at any one time. The pip output of the coincidence stage is applied to the track gate generator, which produces a positive track gate pulse 1.6 μsec wide (H of FO 1). The position of the track gate pulse is in the center of the 2000-yard and 40,000-yard unblanking gates, which satisfies the requirement of having the target located in the center of these two sweeps when automatically tracking in range. The track gate is also applied to the range system, where its position is time-compared with that of the trigger for accurate range determination.

This is the principle of operation of the reference chain section.

We have developed gates with a definite time relationship to each other, developed voltages which allow us the desired range presentation on indicators, and

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developed a track gate which gives us an accurate means of determining the range of any selected target.

Phase chain. The phase chain is supplied with the master timing frequency (82 kHz) and two divider output frequencies (4.1 kHz and 410 Hz). This, in effect, gives the phase chain three operational channels: the 82-kHz, 4.1-kHz, and 410-Hz channels. The outputs of the phase chain are a trigger pulse that occurs at different time periods (depending on the movement of the range motor), and a 400,000-yard sweep drive voltage.

Foldout 1 also shows the waveforms developed within the phase chain. Notice that each waveform is identified with a letter. The letters represent where these waveforms are developed in the phase chain of the block diagram (FO 1).

The three basic frequency signals from the reference chain are applied to the phase-shift selsyns in the range system through three phase networks.

The purpose of each phase network is to develop three signals 120° out of phase with each other. There are three phase networks, one for each input frequency. Only the 82-kHz signal is applied directly to its phase network. The 4.1-kHz and 410-Hz signals coming from the dividers in the reference chain are in the form of square waves (B and C in FO 1). Before being applied to their selsyns, these voltages must be reconverted to sine waves. This is done by selective amplifiers using feedback (not shown in FO 1). In these amplifiers, all harmonics of the fundamental frequency are canceled by degenerative feedback. The outputs are, therefore, limited to the fundamentals of the respective pulses.

The phase networks consist of a phase splitter and a three-phase RC network. The phase splitter (a paraphase amplifier) develops two signals 180° out of phase. These two signals are applied to the three-phase network, where three voltages 120° out of phase are developed. The three outputs of each phase network are applied to the stator windings of their respective selsyns in the range system.

There are three phase-shift selsyns (82 kHz, 4.1 kHz, and 410 Hz), the rotors of which are ganged together and connected to the range motor. Although the rotors are ganged together, each has a different gear ratio to the main drive. For each 2000-yard change in range, the rotor of the 82-kHz selsyn makes one complete revolution. For each 40,000-yard change in range, the rotor of the 4.1-kHz selsyn makes one complete revolution. Finally, for each 400,000-yard change in range, the rotor of the 410-Hz selsyn makes one complete revolution. Remember, each complete revolution of a selsyn rotor means that its output is shifted 360° when compared with the input of its phase network.

The output of the 82-kHz selsyn is sent to an amplifier, cathode follower, and a clipping amplifier (none of which are shown in block diagram FO 1), which produce a series of positive pips (A of FO 1). These positive pips are applied to the second coincidence stage which also receives the output of the second gate multivibrator. At this point, let's leave the 82-kHz signal and develop our 410-Hz input to this stage.

The output of the 4.1-kHz selsyn is amplified, clipped, and applied to a square-wave amplifier (not shown in FO 1). This square wave is differentiated and applied to the first coincidence stage (E of FO 1), which also receives the gate from a 410-Hz gate multivibrator.

The output of the 410-Hz selsyn is amplified, limited, and clipped, and then applied to a square-wave amplifier (not shown in block diagram FO 1). The square wave (D of FO 1) is differentiated and the negative pin is used to trigger the first gate multivibrator.

There are four gate multivibrators and three coincidence stages. The first gate multivibrator is triggered by the negative pip produced from the output circuit of the 410-Hz selsyn. The output of this first multivibrator is a gate approximately 230 μsec wide, which is variable in width (D of FO 1). This gate is applied to the first coincidence stage. The other input needed to cause the coincidence stage to conduct is the differentiated 4.1-kHz positive pip (E of FO 1). Since the frequency of these pips is 4.1 kHz, the positive pips occur approximately 244 μsec apart. This prevents the coincidence stage from conducting more than once when the 410-Hz 230-μsec gate is present. Therefore, the coincidence stage produces one negative pip for each applied 410-Hz gate, or one for every tenth 4.1-kHz pip (F of FO 1).

The negative pip output of the first coincidence stage is applied to the second gate multivibrator, where a positive 10-μsec pulse is developed (G of FO 1). The positive 10-μsec pulse is applied to the second coincidence stage along with the 82-kHz pip previously discussed.

When both the 10-μsec gate and the 82-kHz pip are present at the second coincidence stage, the tube conducts and produces a negative pip output (H of FO 1). Since the frequency of the 10-μsec gate is 410 Hz, there are 200 of the 82-kHz pips for each 10-μsec gate ($200 \times 410 = 82$ kHz). The 10-μsec gate selects only one of the 82-kHz pips, since these pips are 12.2 μsec apart. The negative pip output is applied to the third gate multivibrator.

Let's stop now and think of what has actually been happening up to this point. We started out with three frequencies from the reference chain ranging from 410 Hz to 82 kHz. Since all we want is to develop a trigger and sweep drive voltage at a frequency of 410 Hz, why didn't we just use one 410-Hz selsyn and its associated circuitry and forget all about the other two selsyns, their associated circuitry, and the three coincidence stages? The answer, as you have probably guessed, is the need for range accuracy. Our first coincidence was with a 410-Hz gate and an 82-kHz pip, providing us with a 200:1 selection, or 200 times more resolution than we would have using a single 410-Hz channel.

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The output of the second coincidence stage is sent to the third gate multivibrator. This gate multivibrator produces a positive pulse, approximately 44 μsec wide (I of FO 1). This pulse is sent to the 400,000-yard sweep generator. The pulse is also differentiated and used to trigger the fourth (last) gate multivibrator. When triggered, the fourth gate multivibrator produces a positive 10-μsec pulse (J of FO 1). This pulse is sent to the third (last) coincidence stage.

When the phased 82-kHz pips and the positive 10-μsec pulse output from the fourth gate multivibrator are present, the third coincidence stage conducts. As in the second coincidence stage, one out of every two hundred 82-kHz pips is selected. The resultant negative pip is applied to a blocking oscillator.

When triggered, the blocking oscillator produces positive and negative triggers. The positive triggers (K of FO 1) are sent to the range system for range error detection, and to the indicator system to initiate the PPI sweep. The negative trigger is sent to the transmitter.

The sweep generator is a sawtooth generator, whose output begins with the trailing edge of the 44-μsec gate from the third gate multivibrator. The sawtooth is applied to a cathode follower (not shown in FO 1) and sent to the 400,000-yard range indicator.

We now have satisfied all of the requirements of the synchronizing system. We have developed gates which are time-fixed and a trigger at any established PRF that constantly varies in time with changing range. Although this is not the only method by which these requirements could have been met, it is one method actually used. It would have been just as easy to phase those gates we generated in our reference chain as it was to phase the trigger. This, of course, is a matter of design. The applications of the principles involved are still the same.

Exercises (460):

Refer to foldout 1.

1. What is the time relationship between the output of the first coincidence stage in the phase chain and the trigger to the modulator?

2. What is the width of the track gate?

3. What two signals are used to develop the track gate?

4. What two signals develop the modulator trigger?

5. Which trigger or gate is stationary on the indicators and why?

461. List the types of equipment and characteristics of waveforms required to test the operation of the synchronizer.

Synchronizer Test Principles. Synchronizer test principles are based on waveform analysis and require the use of either an oscilloscope or synchroscope. Either of these two instruments provides a visual display of voltage variations with respect to time.

Autotrack radar synchronizers develop many types of waveforms of various frequencies and durations. The characteristics of the test set must, therefore, cause minimum distortion in order to allow accurate measurement of the waveforms to be tested.

To effectively analyze the synchronizer waveforms, you must first know the characteristics of the waveform to be tested. For example, you must know the desired shape of the waveform you are testing—the frequency, the width, and the amplitude. This information is usually available in the equipment manuals in the form of pictures of desired synchronizer waveshapes.

We will discuss the basic principles of oscilloscope operation, which you will use in your maintenance duties to analyze typical synchronizer waveforms. You select the type of oscilloscope required for a particular test by considering such characteristics as input frequency response, input impedance, sensitivity, and various sweep speeds required to test the waveform.

The input frequency response of the test set determines the maximum input frequency measurement capability. If a wide range of waveform frequencies is to be tested and measured (remember, typical autotrack synchronizer waveform frequencies range from 410 to 82,000 Hz), the set must be able to provide accurate measurements over the complete frequency band.

The input impedance of the test set must be high as compared with that of the circuit which produces the waveform to be tested. Low test set impedance will cause distorted waveforms to appear on the CRT, giving you the false impression that circuit components are causing the waveform distortion.

The distance that the spot on the CRT screen may be moved in either the horizontal or vertical direction by a known DC potential determines the sensitivity of the test set. This sensitivity can be calculated by measuring the distance the spot moves and dividing this distance by the amount of voltage causing the movement.

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The sweep speed characteristic of the test set determines how many sweeps per second are furnished the CRT. This is particularly important when you wish to view a specific number of input waveforms on the sweep. For example, if you have a waveform occurring at 2000 Hz and you wish to view two of these waveforms, you must have a sweep speed of 1000 Hz available.

Exercises (461):

1. List the types of equipment used to test the synchronizer.

2. What effect should the test equipment have on the signal being tested?

3. In order to effectively use the test equipment, what must you first know?

4. What characteristics should be considered when selecting the test equipment for checking the synchronizer?

4-2. Range Determination

There are two widely used methods of range tracking in autotrack radars: (1) target splitting, which consists of two videos (nondelayed and delayed) and one gate, and (2) pulse splitting, which consists of one video and two gates (early and late). Both methods are based on the amount of coincidence that takes place between the return video and the gate or gates. The target-splitting method is used with a pulse synchronizer, while the pulse-splitting method is used with a systems synchronizer. Let's discuss the target-splitting method first.

462. Using a functional diagram of a target-splitting range-tracking system, state the purpose of selected blocks.

Target Splitting. Figure 4-3 is a functional diagram of a target-splitting range-tracking system. In this system, the role of the synchronizer is to furnish a trigger (range preknock) to the track range computer. Recall that this trigger is generated 11 to 69 microseconds prior to the firing of the transmitter. This permits the development of the required ranging signals at the times they are needed.

The tracking range computer produces a track range mark that is movable in time. The position of the track range mark is indicative of the position of the range gate on the indicators. The output of the track range computer is sent to the pulse demodulator.

The pulse demodulator is composed of the following units which have a direct bearing on range determination: 0.44-microsecond delay network, pulse generator, and range error channel.

The pulse generator receives the track range mark and produces four output pulses. These pulses are a 500-yard sweep expansion pulse, a 100-yard range notch, a 35-yard range gate, and a 1.2-microsecond clear-out pulse. The output that directly affects the operation of the ranging circuitry is the 35-yard range gate. It is fed to the range error channel.

The range error channel receives the 35-yard range gate from the pulse generator, a nondelay video signal, and a 0.44-microsecond delay video signal. Any time difference between the video signals and the range gate results in a DC error voltage indicative of the range error. This voltage is fed to the range modulator.

The range modulator accepts the DC range error signal from the range error channel and converts it to a 400-Hz signal. This signal is used to drive the range servo group.

The range servo group drives the range system and repositions the track range mark and the range-indicating dials on the radar console.

Exercises (462):

Refer to figure 4-3.

1. What is the purpose of the synchronizer?

2. What is the purpose of the tracking range computer?

3. What is the purpose of the range modulator?

4. What is the purpose of the range error channel?

5. What is the time relationship between the range preknock pulse and the sync pulse?

463. Using a tracking range computer diagram, identify selected waveshapes and their timing relationships.

Tracking range computer. As we have already learned, the tracking range computer produces a track

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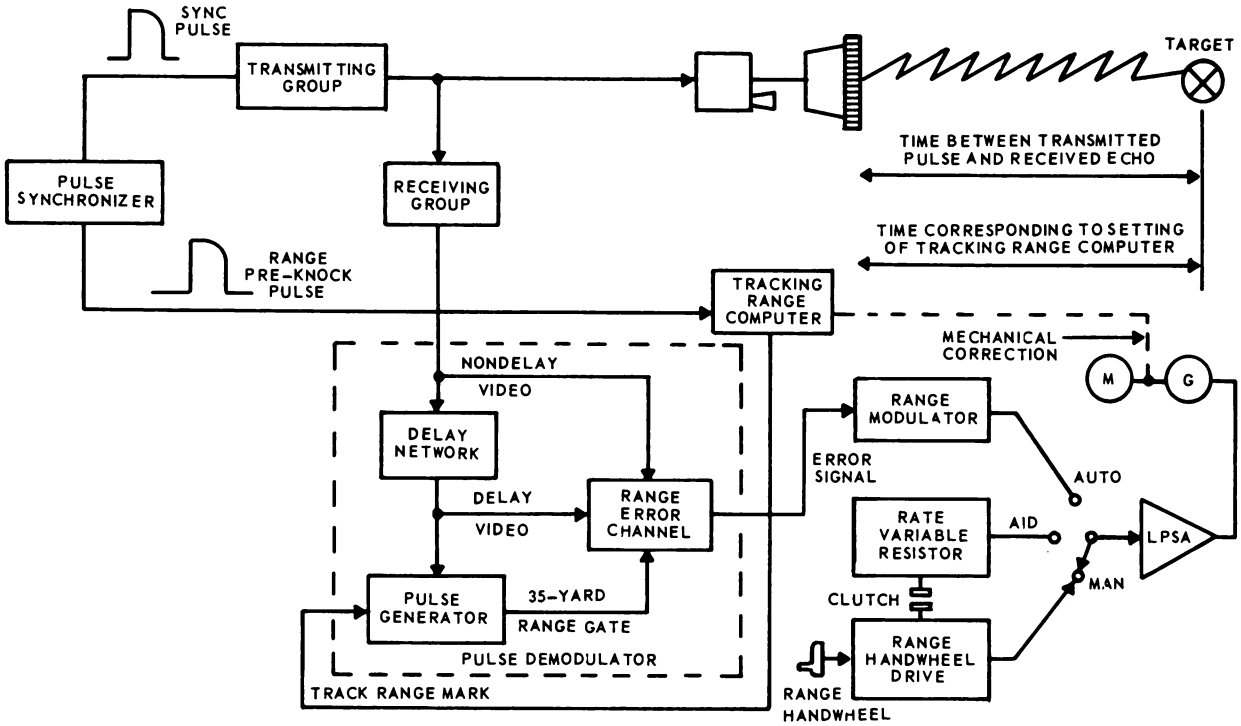

Figure 4-3. Target-splitting range system.

range mark that is movable in time and represents the range of the range gate displayed on the indicators. This unit is accurate to ±0.06 microseconds. The block diagram and timing chart of the tracking range computer are shown in foldout 2. We will briefly discuss each block on the diagram and the outputs derived from them. In order to understand the operation of the complete track range computer, we must develop a thorough understanding of the timing relationship that exists between the various units. As we discuss the function of the units within the tracking range computer, study the waveforms from each unit and their relationship to the other waveforms.

• MAIN GATE GENERATOR: The main gate generator produces a negative, variable width square wave that is used to trigger the timing-wave generator and phantastron. It is a one-shot multivibrator consisting of dual triodes V8, V9, and stop gate generator V7. This circuit differs from the conventional one-shot multivibrator in that V9 has been added to assure rapid recovery during quiescence.

• TIMING-WAVE GENERATOR: The timing-wave generator receives the negative pulse output of the main gate generator and produces a sine-wave oscillation lasting as long as V8A is conducting. This precise sine wave establishes a reference for generating the timing pips that are used in range measurements.

• PIP GENERATOR CHANNEL: The pip generator channel squares and differentiates the 81.955-kHz sine wave from the timing-wave generator to produce a train of pips. These pips are spaced at 2000-yard intervals and are used to trigger subsequent tracking range computer circuits for range measurement.

• PHANTASTRON CHANNEL: The phantastron channel receives the positive, variable width, main gate from the main gate channel and produces a sawtooth that decreases linearly for the duration of the main gate generator output. The phantastron sweep output is applied through cathode follower V10 to one grid of dual-triode comparator V12.

• PIP SELECTOR CHANNEL: The negative-going phantastron output from the cathode of V10 is applied to comparator tube V12, where it is compared with the DC voltage from range variable resistor R8 in the timing-wave generator. Variable resistor R8 requires 10 turns to complete 200,000 yards of range; phase shift resolver B6, to which the variable resistor is mechanically connected, requires 50 turns to cover the same range. (4K yards per revolution.)

• TRACKING RANGE MARK CHANNEL: The tracking range mark channel produces a 0.2-μsec range mark. This range mark, which bears a constant time relationship with the selected pip, is used as the timing mark for the automatic tracking circuits of the pulse demodulator.

• TRACKING RANGE GATE CHANNEL: The positive pulse from the pip selector channel is used in the tracking range gate channel to produce a positive 13 ± 3-volt, 30-μsec range gate. The tracking range gate channel supplies a positive 30-μsec pulse to the tracking range mark channel.

Exercises (463):

Refer to foldout 2.

1. What outputs are furnished by the main gate generator?

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2. Draw the output waveshape from the pip generator channel.

3. What determines the start of the 12-μsec gate?

4. The main gate generator is reset how long after pickoff?

5. What is the time relationship between the selected pip and the tracking range mark?

464. Given a range diagram, describe outputs from specified units in selected range modes.

We have discussed each of the units of the target-splitting range system in the three preceding objectives. Now we will look at what effect these units have on the overall operation of the range system.

Let's look once again at figure 4-3. This figure shows the complete target-splitting system including the servos. You can see that there are three modes of operation shown. They are selected by the switch immediately to the left of the low-power servoamplifier (LPSA).

The range handwheel drive furnishes an output to the range servosystem when the switch is in the MAN or AID position. The output is taken directly in the MAN position. This output is a 400-Hz signal whose amplitude is determined by the speed the handwheel is tuned and whose phase is determined by the direction you turn the handwheel.

Notice also that the handwheel is mechanically connected through a clutch to the wiper arm of the rate variable resistor. The output of this resistor is taken from the wiper arm and connected to the AID position of the switch. When the switch is placed in the AID position, a 400-Hz signal is taken from the wiper arm of the resistor and fed to the LPSA. The amount of signal depends on the speed the handwheel is turned and the phase is determined by the direction of rotation.

In each case, MAN or AID position, the servosystem is mechanically tied to the tracking range computer. This enables the resolver and range variable resistor (R8) to be positioned properly when using manual or aided range. When the range selector switch is placed in the AUTO position, there will not be a change in the positioning of the range servo.

The tracking range computer, pulse demodulator, and range modulator affect the range system only when the range selector switch is in the AUTO position. In this position, the output of the range modulator drives the LPSA. The amplitude of this signal depends on the range error between the range gate and the two videos. The phase of this signal is determined by whether the range gate is displaced toward the delayed or the nondelayed video.

Exercises (464):
Refer to figure 4-3.

1. Describe the output from the range handwheel in the manual mode.

2. Describe the output of the rate variable resistor in the aided mode.

3. Describe the output of the range modulator in the automatic mode.

4. What controls the rate variable resistor in the aided mode?

465. Using the pulse-splitting range-tracking system diagram, describe the operation of selected units.

Pulse Splitting. Range-tracking systems in your career field have many common features. Almost all have similar range modes such as manual, aided, slew, and automatic. Normally, the primary difference is the method of design of the automatic tracking mode. Manual, aided, and slew modes are usually done by moving handwheels or switches which activate motors to drive the ranging system. Previously, you learned the method known as target splitting. Now, we are going to see another method called pulse splitting. Both of these methods are in common usage throughout the career field. We will only examine the automatic mode of operation, since manual, aided, and slewing are similar to the target-splitting method. Refer to figure 4-4 for the following discussion of the pulse-splitting range-tracking system.

The synchronizer system is designed so that the range dials will indicate the distance between the movable transmitting trigger and the track gate (see fig. 4-5). The time relationship between the fixed (reference) track gate and the movable (phased) trigger is the principle by which the range is determined. If the track gate and the transmitting trigger occur simultaneously, the range is zero, since there is no time

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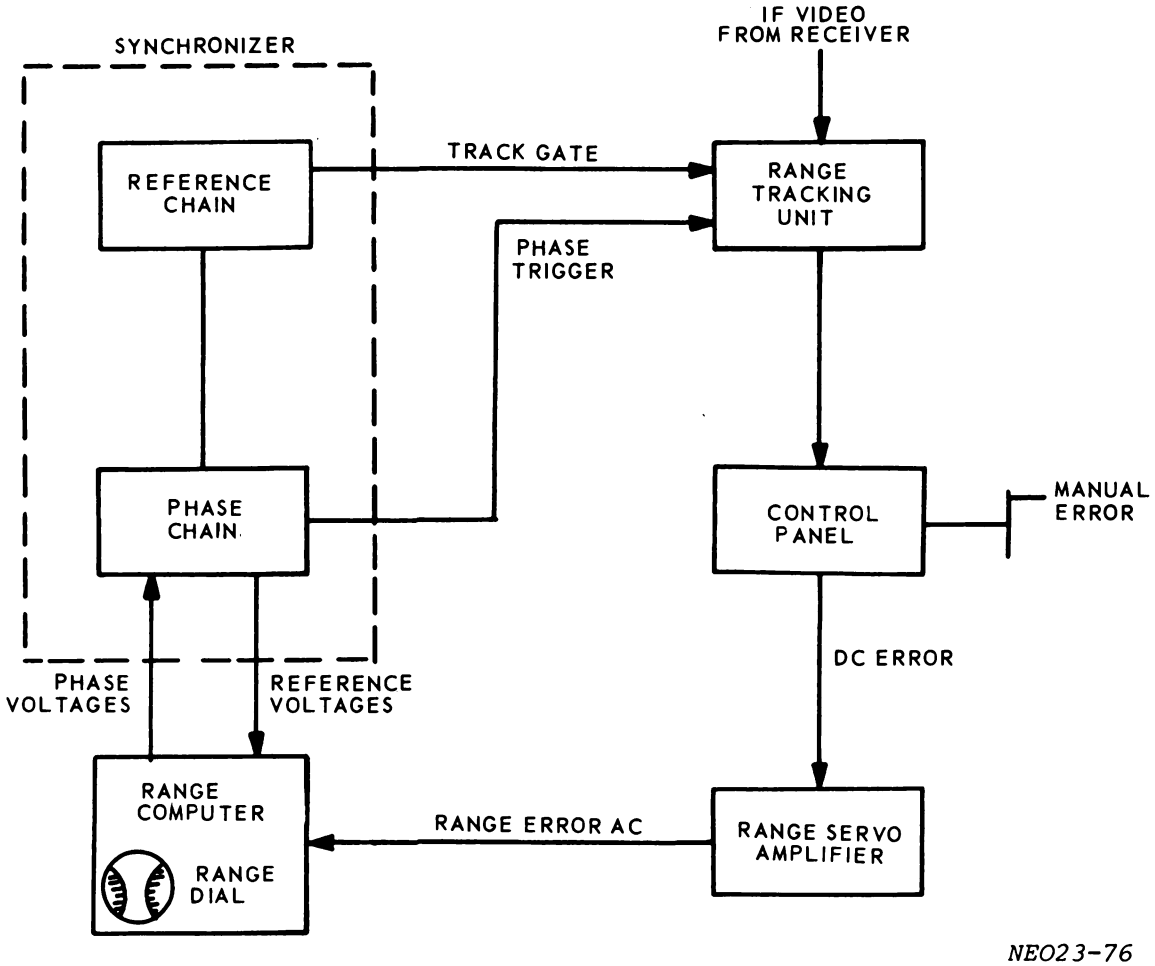

Figure 4-4. Pulse-splitting range-tracking system.

difference between the two (see fig. 4-5,A). As the trigger is moved, the range will change (see fig. 4-5,A and B). Since the trigger fires the transmitter, the returned target video will also be phased. For one particular video, the range of the video from the radar is measured as the time from the transmitter trigger (see fig. 4-6). If the range at which the video occurs and the range at which the track gate occurs are the same, the set is said to be "on target." If there is an error between the two ranges, the phased trigger is shifted and the phased video will follow accordingly. Since the distance between the trigger and the video is more or less fixed, they will both move with respect to the track gate. Once the video is under the track gate, the set is again *on target.* See figure 4-6.

Range-tracking unit. The inputs are the track gate, phased transmitting trigger, and ungated IF. This unit determines whether the video is moving in or out in range. The output is a negative or positive DC voltage, in which the polarity tells the direction of movement and the amplitude denotes the amount of movement.

Control unit. This unit determines which radar mode the radar will operate in—manual, aided, slew, or automatic.

Range servoamplifier. This unit converts DC range error voltage from the control unit into AC range error voltage to drive the range dials.

Range computer. Radar range is measured and displayed on two dials. Phased voltages are sent to the synchronizer to cause the phase chain to move the transmitting trigger and video, thus reducing any range error to zero.

Exercises (465):
Refer to figures 4-4, 4-5, and 4-6 to answer the following questions.

1. What unit causes the video to move when correcting range?

2. What unit converts DC error voltage into AC error voltage?

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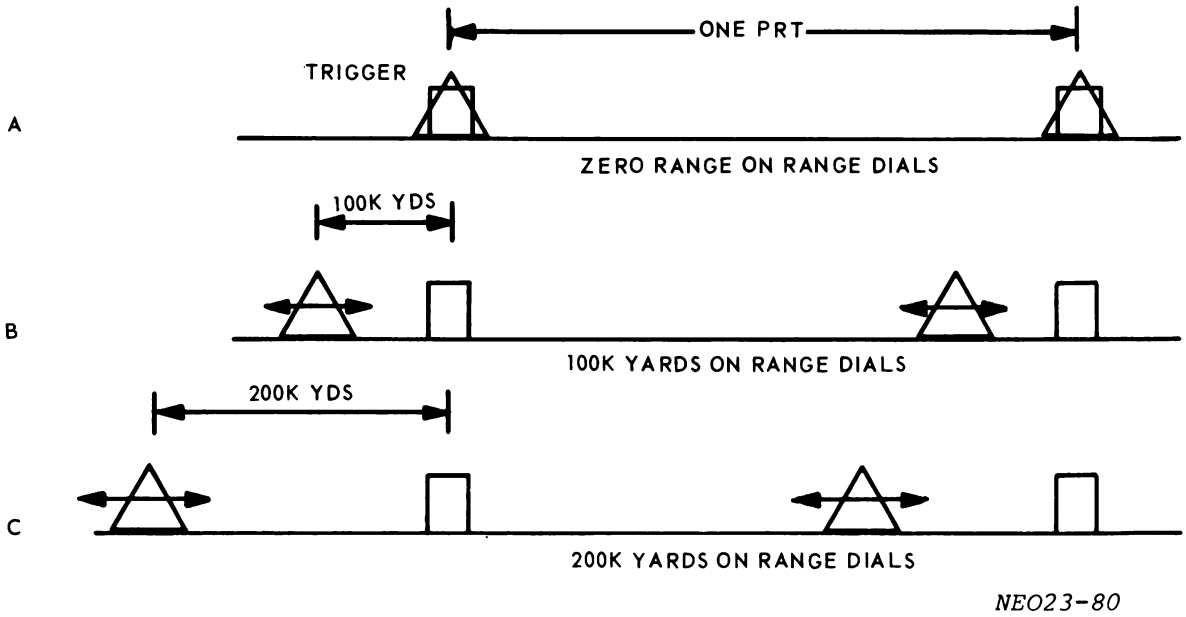

Figure 4-5. Range determination.

3. Radar tracking modes are selected by what unit?

4. When the track gate and the video occur simultaneously, what is this called?

5. What two waveshapes must coin together to be at zero range?

466. State the purpose of the automatic range tracking unit and identify the factors involved in automatic range tracking.

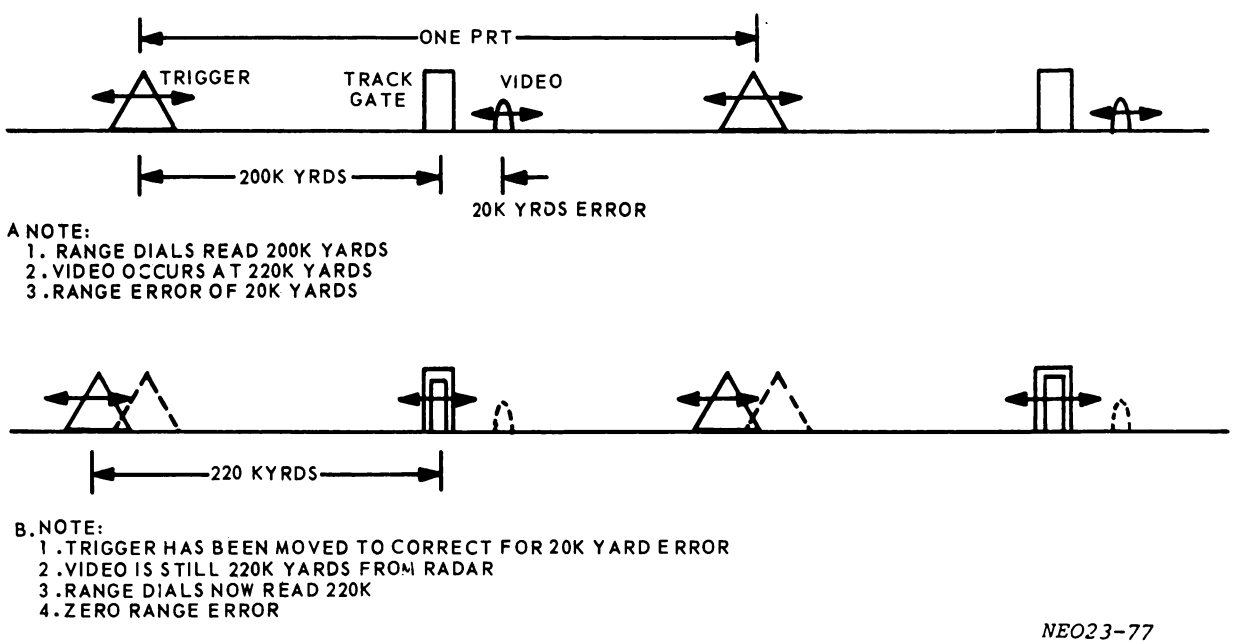

Figure 4-6. Correction for range error.

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Automatic Range-Tracking Principles. The primary purpose of the automatic range-tracking unit is to generate an error voltage proportional to the distance between the center of the target pip (echo) and the center of the track gate, while the echo is in the track gate. The error voltage will be positive or negative, depending on whether the echo precedes or follows the center of the track gate. The distance by which the echo precedes or follows the track gate determines the amplitude of the error voltage.

This time comparison is accomplished by a method known as pulse splitting. The track gate is split into two parts: one part preceding and one part following its midpoint. If the echo is centered in the track gate, then the split is also in the center of the echo and, therefore, the amplitude of the two portions is equal. If the echo is not centered in the track gate, the two portions are not equal in amplitude. Any difference in the amplitude of the two portions is detected by the automatic tracking circuitry. If, in fact, there is a difference in amplitudes, a DC error voltage is produced proportional to the amplitude difference. The polarity of the error voltage depends on which of the two portions is greater in amplitude. This error voltage is used to automatically move the echo toward the center of the track gate until the radar is correctly ranged. If no part of the echo coincides with the track gate, the automatic range tracking unit has lost its automatic tracking capabilities. If this happens, it becomes necessary to move the echo back into the track gate by some other means, such as with the handwheels.

The circuitry which produces the range error voltage is contained in the range error channel. Figure 4-4 shows how the range error channel fits into the overall range system. Figure 4-7 is a more detailed block diagram of the range error channel. In the discussion of the range error channel, we assume that we have idealized tracking waveforms like those shown in figure 4-8.

The primary inputs to the error channel are the modulator trigger and track gate (waveform A of fig. 4-8) and the ungated intermediate frequency signal from the receiver (waveform D of fig. 4-8). As was stated earlier, the track gate (1.6 μsec wide) must be split into two parts to form one 0.8-μsec early gate and one 0.8-μsec late gate. The gate is split with the aid of tracking waves Nos. 1 and 2 (waveforms B and C of fig. 4-8), which are generated in the tracking wave generator.

The ungated IF signal from the receiver, the two tracking waves, and the essentially undelayed track gate form the inputs to the pulse-splitting stage shown in the dotted lines of figure 4-7. The pulse-splitting stage consists of two coincidence tubes: the early gate tube and the late tube, both of which are pentodes. The IF signal and the undelayed track gate are applied to the control grids of both pentodes. Tracking wave No. 1 (waveform B of fig. 4-8) is applied to the suppressor grid of the early gate tube. This wave is positive from T_O to the midpoint of T_R. (T_O occurs at the same instant as the leading slope of the modulator trigger; T_R is the track gate.) Tracking wave No. 2 (waveform C) is positive from T_R to T_O and is applied to the suppressor grid of the late gate tube. The tubes have an IF output only at that time of the track gate which coincides with the positive portions of the tracking waves on their respective suppressor grids. Refer to the track gate portion of waveform A in figure 4-8. Since the early gate tube can amplify the IF signal only during the first half of the track gate, and the late gate tube only during the last half of the track gate, pulse splitting has been accomplished.

Our time comparison between the echo pulse (ungated IF) and the track gate has been made by the pulse-splitting method. Now let's see how this information can be developed into an error voltage. Refer to the ungated IF signal (waveform D in fig. 4-8); notice that the pip, or echo pulse, is to the left of the center of the track gate in waveform A (fig. 4-8). This is during the conduction time of the early gate tube. The early gate tube therefore conducts heavily at this time because of the higher amplitude of the IF signal being applied to the control grid. The late gate tube conducts only during the second half of the track gate, which occurs after T_R. However, notice there is no echo present in that half of the track gate; therefore, the late gate tube does not conduct as heavily as the early gate tube. Keep these facts in mind as we go through our discussion.

The intermediate frequency outputs of the early and late gate tubes are sent to their respective IF detectors (fig. 4-7) where the IF is detected and sent to video separation amplifiers. The purpose of these amplifiers is to prevent loading of the detectors and to amplify the signals (waveforms E and F of fig. 4-8). From the video separation amplifiers, the signal is sent through an inverter in the case of the early gate chain, and through a cathode follower in the case of the late gate chain. The inverter must have a gain of less than unity in order to maintain a balance with the late gate chain where the cathode follower has a gain of less than unity. The signals are now sent to video detectors in their respective chains where a DC voltage is developed across the load resistors in the filters. At the output point, the junction of the two filter load resistors (fig. 4-8), the voltage is equal to one-half the algebraic sum of the output of the early and late gate chains. In this particular case, recall that the early gate tube was conducting more heavily than the late gate tube. Consequently, the sum of the two voltages is a negative DC voltage, one-half of which is the range error. If the echo pulse has been centered in the track gate, the early and late gate chains would have had equal outputs and the error voltage would have been zero.

The DC error voltage is sent through a cathode follower for isolation and then to the range servosystem. The DC error voltage is used as a control voltage in the servosystem where an AC voltage is developed. The AC voltage developed by the servosystem is proportional in amplitude and phase to the amplitude and polarity of the DC signal from the error

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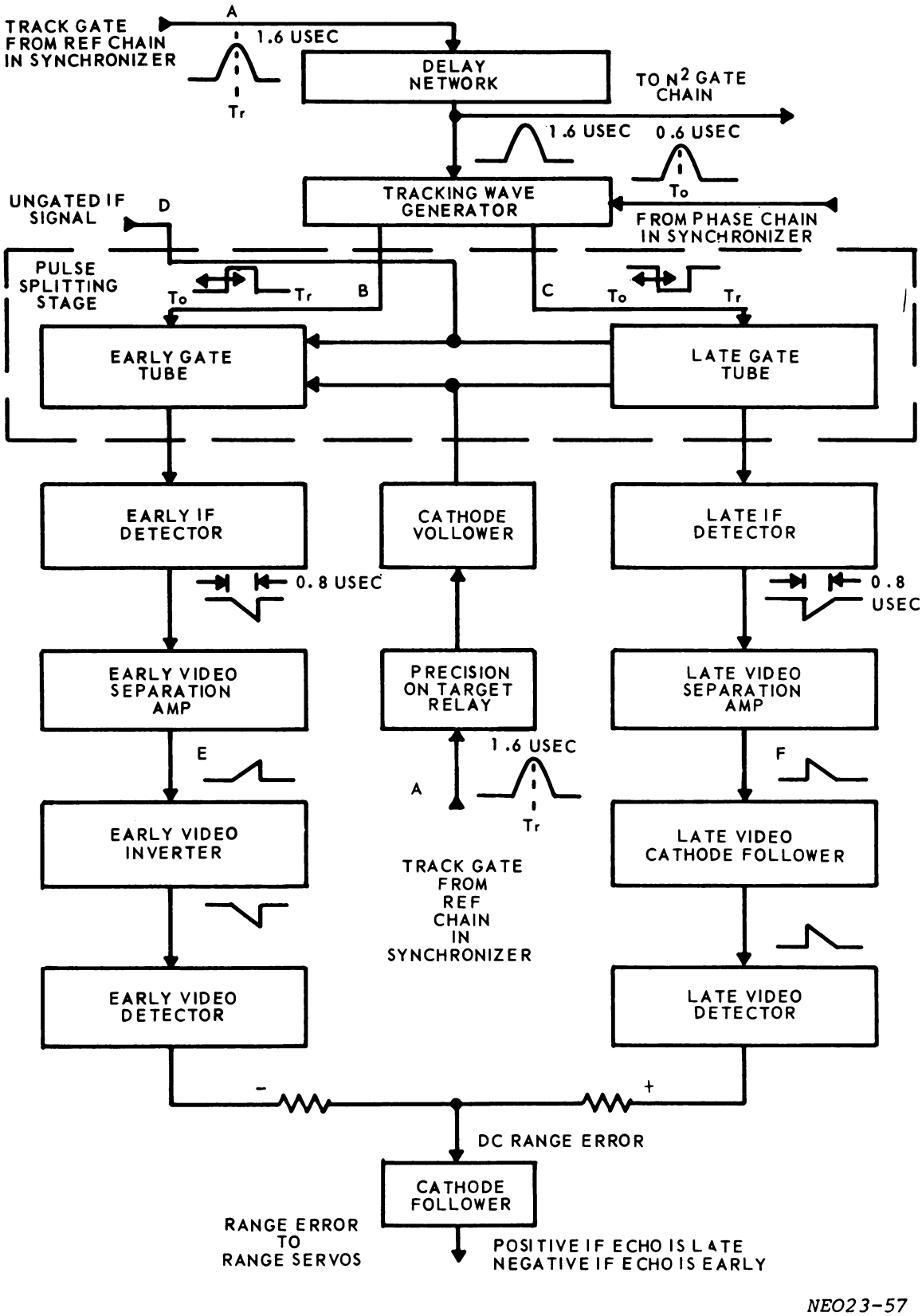

Figure 4-7. Range error channel block diagram.

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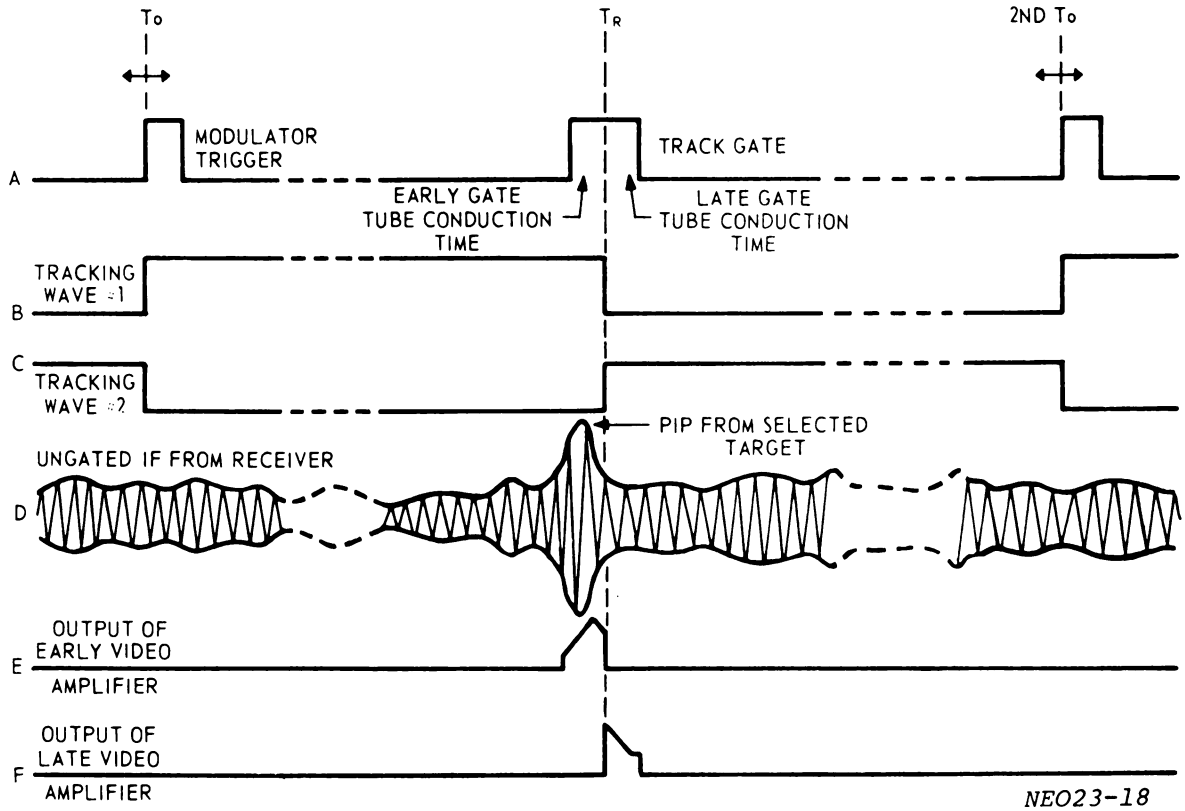

Figure 4-8. Idealized tracking waveforms.

chain. This AC error is used to position the range dials and readjust the phase shifters in the synchronizer which, in turn, readjust the phased triggers in the phase chain with respect to the track gate. You recall, the trigger to the modulator is generated in the phase chain (FO 1). In this manner, the time the transmitter fires is controlled by the range system. Since the track gate is generated by the reference chain and is fixed, the echo pulse can be automatically centered in the track gate for automatic tracking.

Exercises (466):

1. What is the purpose of the automatic range-tracking unit?

2. What method is used to perform automatic range tracking?

3. What are the inputs to the automatic range-tracking unit?

4. What is the output from the automatic range-tracking unit?

5. What must be the relationship of the target and the gates in order to have an output from the automatic range-tracking unit?

467. Describe the check used to determine if the range-tracking system is operating properly and list the alignments which must be verified before aligning this unit.

Range-Tracking Test Principles. Range-tracking test principles are based on waveform analysis and have the same basic requirements as synchronizer tests. These tests can be performed with either an oscilloscope or a synchroscope.

Prior to performing any test or alignments on the range-tracking unit, you must first determine if the unit is operating properly. You can accomplish this with a relatively simple check. Acquire a stationary target and place the radar in full automatic. Switch

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to manual range. Turn the range handwheel slightly to generate a small under-range condition. Return to automatic range. The radar should automatically return the target to the center of the range gate. Once again, place the range in manual. Turn the range handwheel slightly to create a small over-range condition. Return to automatic range. The radar should automatically return the target to the center of the range gate once again. If the radar does not return the target to the center of the range gate in both instances, the range-tracking unit is not operating properly.

Once you determine that the range-tracking unit is not functioning properly, you should check the alignment of certain other units before proceeding with the alignment of the range-tracking unit. These units have a direct effect on the operation of the range-tracking unit. If they are not properly aligned, they can cause the range-tracking unit to appear to be malaligned or malfunctioning.

The units to be checked are the synchronizer, transmitter, receiving systems, and power supplies. These units should be checked to assure that they are properly aligned and functioning correctly. The range-tracking unit power supply should also be checked. When you have satisfied yourself that all of these units have been checked and are operating normal, you can safely proceed with the alignment of the range-tracking unit.

Exercises (467):

1. List the alignments that must be verified before aligning the range-tracking system.

2. What type of target is used to check the operation of this system?

3. When checking the operation of the range-tracking system, what should occur when the range is returned to automatic?

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CHAPTER 5

Antenna-Positioning Systems

IN CHAPTER 4, we discussed the use of the range-error signal in automatic range tracking. We know, of course, we need additional information in order to pinpoint a target in space. In this chapter, we will discuss how the antenna is able to automatically track a target in azimuth and elevation.

The task of tracking in angles is much the same as tracking for range. An error signal must be developed and the error signal must be used to reposition the antenna in such a way as to decrease the error.

5-1. Error Detection

In order to better understand the development of an error signal for positioning the antenna, let's review some of the characteristics of antennas in general.

468. Draw the radiation patterns and compare the gains of the simple dipole, end-fire, and the dipole with a parabolic reflector.

Radiation Pattern. Let's first consider the radiation pattern of the simple dipole antenna. Figure 5-1 is a diagram of a dipole antenna showing the relative field strength. In this case, the antenna is horizontally polarized (radiator in a horizontal plane). Notice that the points of maximum radiation are at 0° and 180° (from the sides of the radiating element). The points of minimum radiation are at 90° and 270° (from the ends of the radiating element).

The radiating element alone would not be suitable for automatic tracking radar applications because of its *dual* radiation pattern (field strength is the same for 180° as it is for 0°). Also, we can see from the diagram that the beamwidth is very wide. With a very wide beamwidth, it would be almost impossible to determine just where within the radiation pattern a target may be. The wide beamwidth is also a waste of RF energy. For accurate angle tracking, we must have a much more *directional* antenna. The *dual* pattern characteristics must be overcome and the RF energy must be concentrated in a narrow beam.

The *end-fire* antenna, shown in figure 5-2, modifies the dual pattern of the single dipole antenna by the precise arrangement of the elements. The spacing of the elements and the phase of the RF energy fed to them causes a canceling effect in one direction and an adding effect in the other direction.

The end-fire antenna does not offer much improvement in beamwidth, and a problem of accuracy would still exist if this antenna were used for automatic tracking. In order to get the very narrow beamwidth necessary for accurate automatic tracking, a dipole antenna is used in conjunction with a parabolic reflector. (See fig. 5-3.) The operating principle of the parabolic reflector can be compared with the reflector used in a spotlight. The radiating element is positioned at a critical point in front of the reflector. When the radiated RF energy strikes the reflector, it is reflected back in a narrow beam. We will discuss later in this chapter how the pattern of the parabolic reflector is used to help produce an angle-error signal.

Antenna Gain. You have probably heard discussions about the effectiveness of one type of antenna as compared with another. During the discussion, you may have heard someone mention that one antenna has a vey high gain. A statement of this kind may lead to some confusion. The term "gain" has an application in antenna discussions. However, it is not specifically

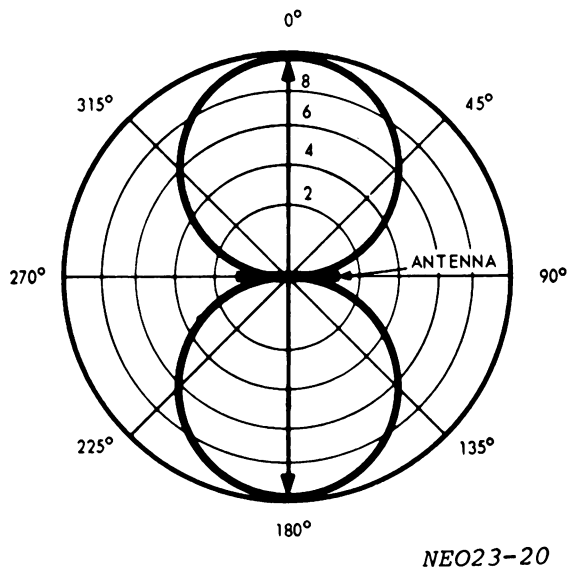

Figure 5-1. Radiation pattern of a simple dipole.

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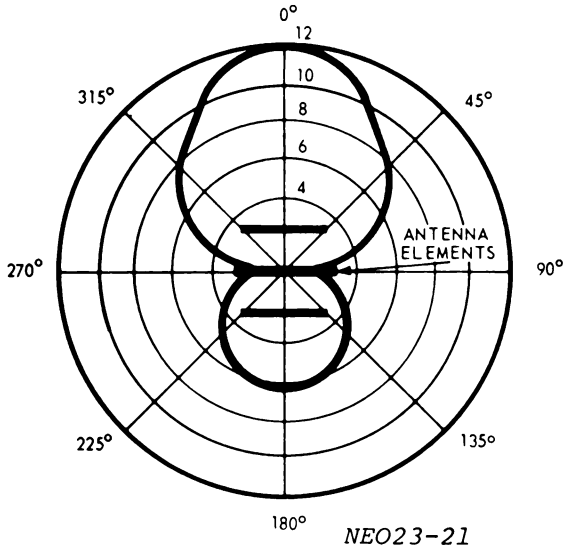

Figure 5-2. Radiation pattern of an end-fire antenna.

the same type of gain that is normally encountered in a discussion concerning amplifiers.

A half-wave dipole antenna is usually used as a standard for measuring the gain of an antenna. If power is applied to the half-wave dipole, it radiates Rf energy. Some of this radiated energy can be detected at some distant receiving station. If the same amount of power is applied to the antenna we wish to test and the conditions are exactly the same for both antennas, the antenna under test produces a field strength, in some directions, which is greater than that produced by the half-wave dipole. The difference in field strength is recorded and converted into decibels. The decibel difference in field strength of the two antennas is said to be the *gain* of the antenna under test.

The more *directional* an antenna is, the more gain that antenna has. This is one reason why the dipole with a parabolic reflector is used in automatic tracking applications. Another reason is the tracking accuracy afforded by the very narrow beamwidth caused by the parabolic reflector.

Directly associated with the antenna is the nutating mechanism, without which the production of an angle-error signal would be very difficult. The nutating mechanism, along with the parabolic reflector, controls the direction of the radiated energy from the antenna. The nutating mechanism is also responsible for the production of the angle-error signal used for angle tracking.

Exercises (468):

1. Draw a diagram of the radiation pattern of a dipole antenna.
2. Draw a diagram of the radiation pattern of an end-fire antenna.
3. Draw a diagram of the radiation pattern of a dipole with a parabolic reflector.
4. What is the disadvantage of using a dipole antenna for an automatic tracking radar system?
5. What is the disadvantage of using an end-fire antenna for an automatic tracking radar system?
6. What advantages does the dipole with a parabolic have for automatic tracking radar system?
7. As an antenna is made more directional, what happens to the gain of the antenna?
8. What must be added to the dipole with parabolic to accomplish automatic tracking?
9. In what terms is antenna gain normally expressed?

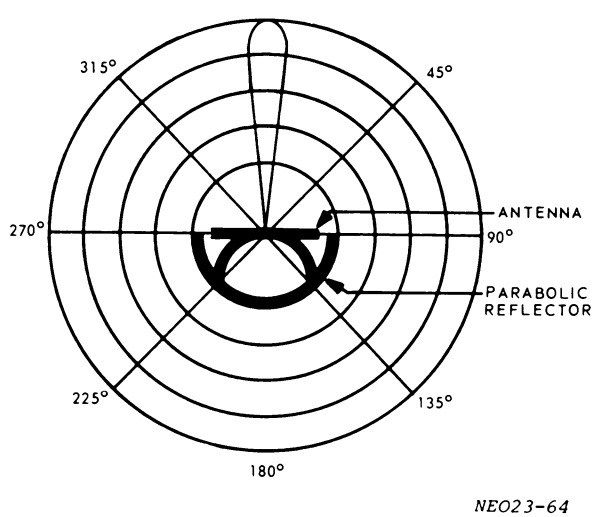

Figure 5-3. Radiation pattern of a dipole with a parabolic reflector.

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10. Which of the antenna systems discussed has the highest gain?

469. State how the RF beam is rotated and identify the factors that control the generation of the angle error.

The nutating action of the antenna can be compared to the headlights of an automobile. When the headlights of an automobile are switched from high beam to low beam, the elements within the light are, in effect, relocated with respect to the reflector. When the switching action takes place, it appears to an observer that the angle of the complete headlight has been changed. Actually, the reflector has not moved. Only the light beam moves.

Angle-Error Generation. The nutating mechanism performs the task of moving the radiation pattern of an autotrack antenna in a circular motion about the axis of the reflector without the reflector actually moving. Refer to figure 5-4,A. You will notice the dipole is not located on the axis of the reflector but is somewhat offset. (Note the drawings in fig. 5-4 are not to scale.) Figure 5-4,B shows the circular motion of the dipole about the axis of the reflector. This action does not change the polarity of the antenna. (Example: If the dipole is horizontally polarized, it will remain horizontally polarized.) The circular movement of the beam is called *conical scanning.*

The beam pattern shown in figure 5-5 is the conical scan basis for automatic tracking. Shown also in this figure are the relative strengths of echos from targets in various positions. If the echo energy from a target in the center of the beam is considered to be a maximum, then the echo energy from a target anywhere outside the center of the beam will be less. The relative amplitude of the returned energy depends upon the angle of return.

Beam rotation. The nutating action of the radiating dipole in some automatic tracking radars causes the center of the RF beam to be offset by 0.9° from the axis of the parabolic reflector (fig. 5-6,A). As the RF beam is rotated, it forms a cone of energy with a vertex angle of 4.8° at the half-power points. The axis of the cone of energy coincides with the axis of the reflector. If a target is on the axis of the reflector, the same amount of energy is reflected regardless of which side of the target the beam is on at any given time (fig. 5-6,B). If the target is off the cone axis by 0.9°, a maximum amount of energy is reflected as the axis of the beam passes through the target. Less than 30 percent of maximum energy is reflected when the beam is on the opposite side of the cone from the target (fig. 5-6,A). Hence, the strength of the echo pulse varies according to the amount the antenna is off target. The nutating mechanism rotates the beam at 30 Hz, so the echo signal is amplitude-modulated with a 30-Hz signal (fig. 5-7). The percentage of modulation depends upon the amount the antenna is off target.

Azimuth error only. When the axis of the reflector is off target in azimuth only, the resulting 30-Hz error signal is in phase or 180° out of phase with the azimuth reference voltage. If the reflector axis is 0.9° offset from the target (fig. 5-8,A), the echo strength varies from 100 percent of maximum to nearly zero. The maximum echo energy is received when the target is on the axis of the RF beam. If the reflector axis is 0.9° off target in elevation but on target in azimuth, the 30-Hz error signal is either in phase or 180° out of phase with the elevation reference voltage.

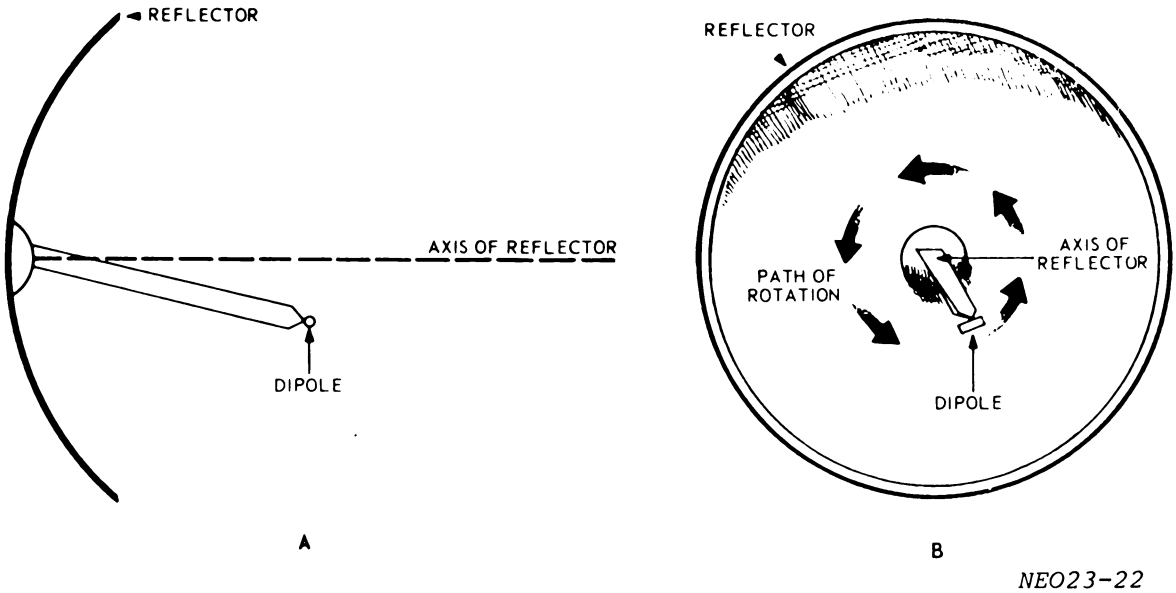

Figure 5-4. Diagram of offset and rotating dipole.

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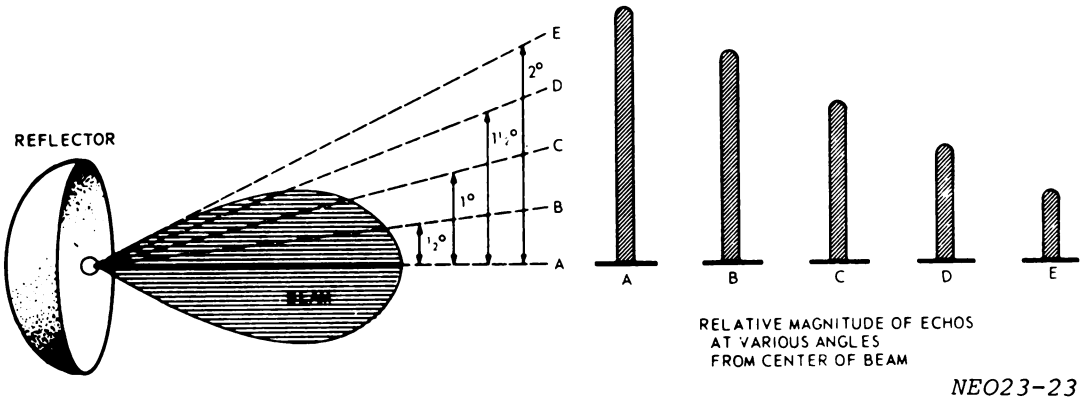

Figure 5-5. Relative magnitude of echoes from various angles.

Azimuth and elevation error. When the reflector axis is off target in both azimuth and elevation (fig. 5-8,C), the 30-Hz error signal is not in phase or 180° out of phase with either reference voltage. The phase relationship between the error signal and the reference voltages is determined by the direction the reflector axis is off target.

No angle error. When the axis of the reflector points directly at the target, the returning echo signals have the same amplitude for every position of the RF beam. When this condition occurs, there is no 30-Hz error signal. This is an on-target condition.

Exercises (469):

1. How is the RF beam rotated?

2. What term is used to describe the circular movement of the RF beam?

3. What is the frequency of rotation of the RF beam?

4. What determines the percent of modulation of the RF beam?

5. Describe the error signal when the reflector points directly at the target.

6. What error exists when the 30-Hz error signal is not in phase or 180° out of phase with either reference voltage?

470. State the purpose and operational characteristics of the reference generator, phase corrector, and secant corrector in the detection of angle error.

If the radar is not directly on target, correction depends on detecting the angle-error signal. In order to detect an angle-error signal, reference voltages must be available for comparison.

Angle-Error Detection. The 30-Hz azimuth and elevation reference voltages are generated by the reference generator. The reference generator is driven in synchronization with the main drive shaft of the nutating mechanism. The rotating eccentric weight of the nutating mechansim is also driven in synchronization with the main drive shaft by means of a drive chain connecting the two. Since the eccentric weight causes the nutating motion and hence the 30-Hz error signal, it is apparent that the error signal and the reference voltages produced by the generator are in exact synchronization. The two-phase generator, which is driven directly by the antenna nutating drive motor, furnishes both the azimuth and elevation reference voltages. The stator of the generator is composed of two coils, mounted at right angles to each other, to produce two voltages 90° out of phase when the generator rotates. The voltage induced into one of the stator coils is the azimuth reference voltage and the voltage induced into the other is the elevation reference voltage.

Let's take a moment or two in order to review what we have discussed so far as angle tracking is concerned. The input to the system is a 30-Hz signal applied to the automatic angle-tracking unit. This 30-Hz signal input to the automatic angle tracking unit results from conical scanning. The phase of the 30-Hz signal modulation envelope is determined by the direction of the target with respect to the axis of the reflector. An output proportional to the percentage of modulation is fed to the azimuth and elevation tracking unit. Here, the phase of the error signal is compared with that of the 30-Hz voltage from the reference generator, which is driven by the antenna nutating

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drive motor. The control voltage from the azimuth and elevation tracking unit is a push-pull DC voltage which is fed to the azimuth and elevation motor generator (amplidynes). The output of the motor generators is applied to the drive motors to control the direction, distance, and velocity of antenna movement in azimuth and elevation. The antenna moves until the error voltage is eliminated—that is, until the 30-Hz modulation envelope disappears.

There are a couple of important considerations that must be made in order to insure tracking accuracy. When the error signal is computed, range must be taken into account. Also, the angle of elevation has an effect of azimuth tracking. These effects require certain corrections to the error signal to insure accurate tracking.

Phase correction. The angle information contained in the 30-Hz signal from the receiver is subject to an error that increases as the range of the target increases. If no time elapsed between the firing of the pulses and their reflected return to the antenna, the phase difference between the 30-Hz error signal and the 30-Hz reference voltage would be a measure of the target position with respect to the antenna. Since a certain time does elapse, there is a phase difference between the two which increases with range. In order to maintain accurate angle tracking, it is necessary to shift the phase of the reference voltage by an amount proportional to the range of the object being tracked. This is done by the phase correction circuits in the phaser and the range computer, where the phase of the output of the reference generator is shifted before it is applied to the azimuth and elevation tracking unit. The phase shift at maximum range is approximately 13°. (See fig. 5-9.)

Secant correction. When automatic angle tracking is in progress, the error signal for a given amount of azimuth error is greater at low elevation angles than at high elevation angles. This can be illustrated by assuming an aircraft at 100 miles slant range and 10° elevation angle. If this aircraft moves 10 miles laterally, there will be a small change in azimuth for this given error signal. If this same aircraft were at a high elevation angle of say 80°, and the aircraft moves laterally 10 miles the same as before, there is the same amount of error signal. However, there is a much greater change in azimuth than before. Figure 5-10 illustrates this. As a result, the amplified error signal applied to the azimuth drive motor has to move the antenna more degrees in azimuth at high elevation angles and fewer degrees at low elevation angles for the same amount of error signal. For this reason, a correction circuit is incorporated in the radar set to increase the gain of the azimuth channel as the elevation angle increases. The circuit is termed a "secant corrector" because the gain of the azimuth channel is varied in steps proportional to the secant of the elevation angle.

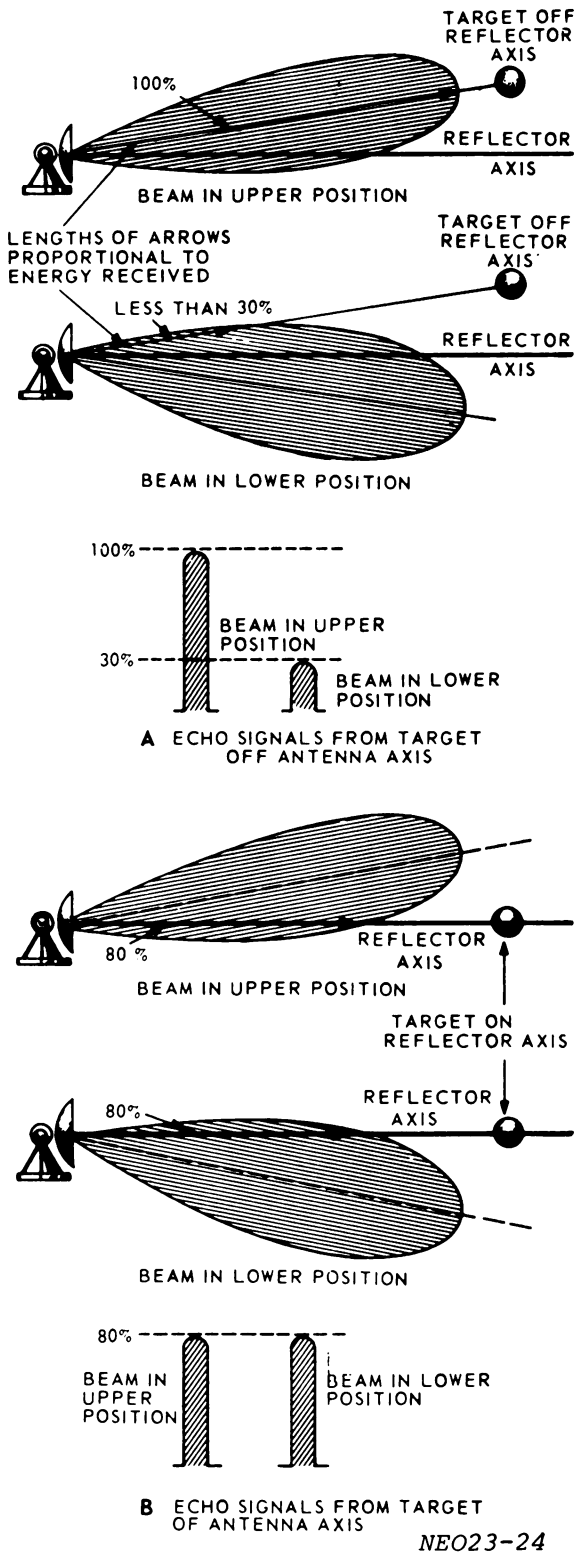

Figure 5-6. Echo signals produced when dipole nutates.

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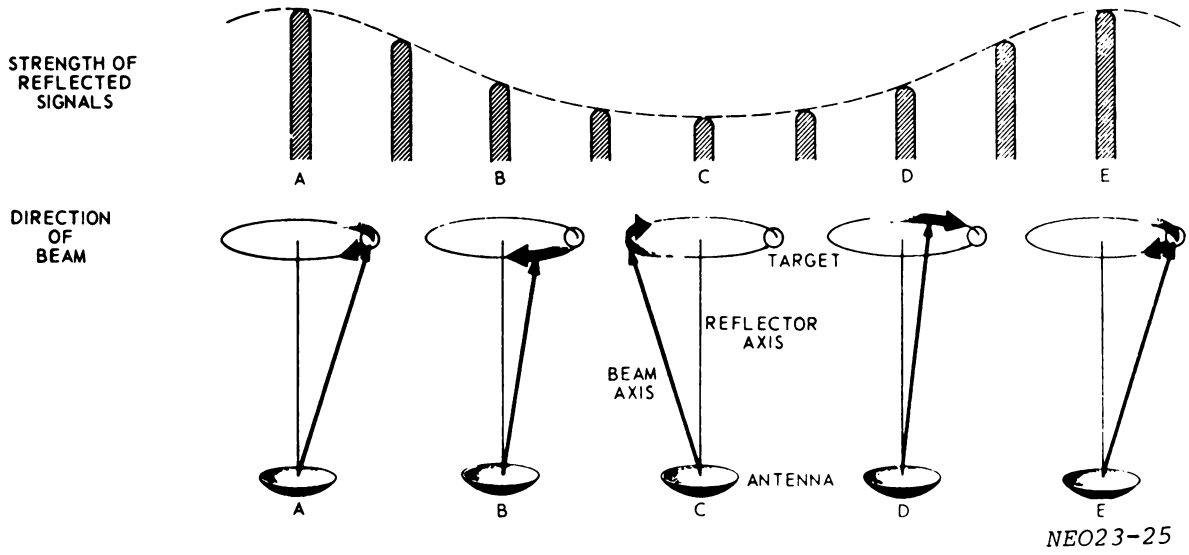

Figure 5-7. Production of 30-Hz variations in echo signals.

Exercises (470):

1. What is the purpose of the reference generator?

2. What is the purpose of the secant corrector?

3. What is the purpose of the phase corrector?

4. What is the phase relationship of the output voltages of the reference generator?

5. What effect does a decrease in target range have on the 30-Hz signal from the receiver?

6. The error signal for a given amount of azimuth error is the least at what elevation angle?

7. How does the secant corrector vary the gain of the azimuth channel?

471. Given a list of characteristics of manual antenna positioning, identify the mode of operation to which each characteristic applies.

Manual Antenna Positioning. The manual types of antenna positioning which use servomechanisms include manual, remote, combinations of manual and remote, sector scan, and PPI operation. In these modes of operation, the automatic angle-tracking unit and the reference generator are disconnected from the antenna-positioning circuits.

Rotation of the stator of the azimuth control selsyn in the antenna-positioning system by means of the azimuth handwheel causes a 60-Hz voltage to be induced from the rotor which is held stationary by a magnetic brake. (In automatic mode, the rotor is released and rotated by a followup motor, to keep it at a null so there will be no slewing of the antenna when switching from an automatic mode back to a manual mode.) This voltage is applied through the control panel to the stator of the azimuth selsyn transformer. From the rotor of this selsyn transformer, an error voltage is taken to the azimuth and elevation tracking unit. Here, the 60-Hz error signal is compared with the 60-Hz line voltage which is used as a reference voltage. The resulting error output runs the azimuth drive motor, positioning the antenna and rotating the rotor of the azimuth selsyn transformer at the same time, until the selsyn arrives at a null point. In addition to the normal manual mode of operation, either azimuth or elevation can be kept in manual operation when the set is in automatic mode. This is done by means of two switches: a MANUAL AZIMUTH switch on the front panel of the azimuth and elevation tracking unit and a MANUAL ELEVATION switch on the antenna -positioning control unit.

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In remote control of the antenna, a control selsyn in the set replaces the control selsyn in the antenna positioning control unit, providing voltage to the stators of the selsyn transformers.

During sector scanning, the input to the stators of the azimuth selsyn transformer remains fixed. The output of the rotor goes to the sector scan unit to control the circuits there, and the output of the sector scan unit is applied to the azimuth and elevation tracking unit as error voltage. The sector scan unit permits scanning of a portion of the azimuth angle. The size of the sector angle may be varied from 30° to 120°. A steady error voltage, which causes the antenna to rotate in one direction, is provided to the azimuth and elevation tracking unit. This rotation builds up the error signal out of the azimuth selsyn transformer until it reaches sufficient amplitude to cause the sector scan unit to switch over, reversing the antenna rotation.

PPI scan operation closely resembles manual operation, except that the PPI scan motor replaces the azimuth handwheel in positioning the stators of the azimuth control selsyn. Helical scanning is ordinarily obtained with this type of operation. The antenna elevates slowly while rotating in azimuth, at the rate of 20° elevation for every six revolutions in azimuth. During the seventh revolution, it returns to its original point to begin again. On some set, there is an ELEVATION SCAN switch mounted on the antenna-positioning control unit. When this swtich is in the ON position, helical scan is obtained. When the switch is OFF, only azimuth rotation results. The position of the antenna (in elevation) when the elevation scan switch is activated determines the minimum elevation of the helical scan pattern.

Exercise (471):

1. Match the statements in column A with the appropriate modes of operation in column B by writing the correct letter in the blank provided.

Column A	*Column B*
_____ 1. Rotation of the stator of the azimuth control selsyn by means of the azimuth handwheel.	a. Manual.
_____ 2. A control selsyn in the set replaces the control selsyn in the antenna-positioning unit.	b. Sector scan.
_____ 3. Permits scanning of a portion of the azimuth or elevation.	c. Remote.
_____ 4. The azimuth handwheel is replaced with a scan motor.	d. PPI.
_____ 5. The input to the stators of the azimuth selsyn transformer remains fixed.	
_____ 6. A 60-Hz voltage is induced from the rotor which is held stationary by a magnetic brake.	

5-2. Antenna Drive System

The block diagram of the antenna-positioning system is illustrated in foldout 3. This drawing will be referred to throughout this section.

472. Given a list of the units in the antenna-positioning system, identify the purpose of each unit.

Automatic Tracking Unit. The automatic tracking unit produces an error voltage which indicates the direction and amount the antenna is off target when the radar set is tracking automatically.

Error signal amplifier. This stage functions as an amplifier and the output is fed to the balanced amplifier through a center-tapped transformer.

Balanced amplifier. This state is a double triode. The two input signals are obtained from the transformer, which has its secondary winding grounded at the centertap. The two input signals are equal in amplitude but 180° out of phase with each other. The

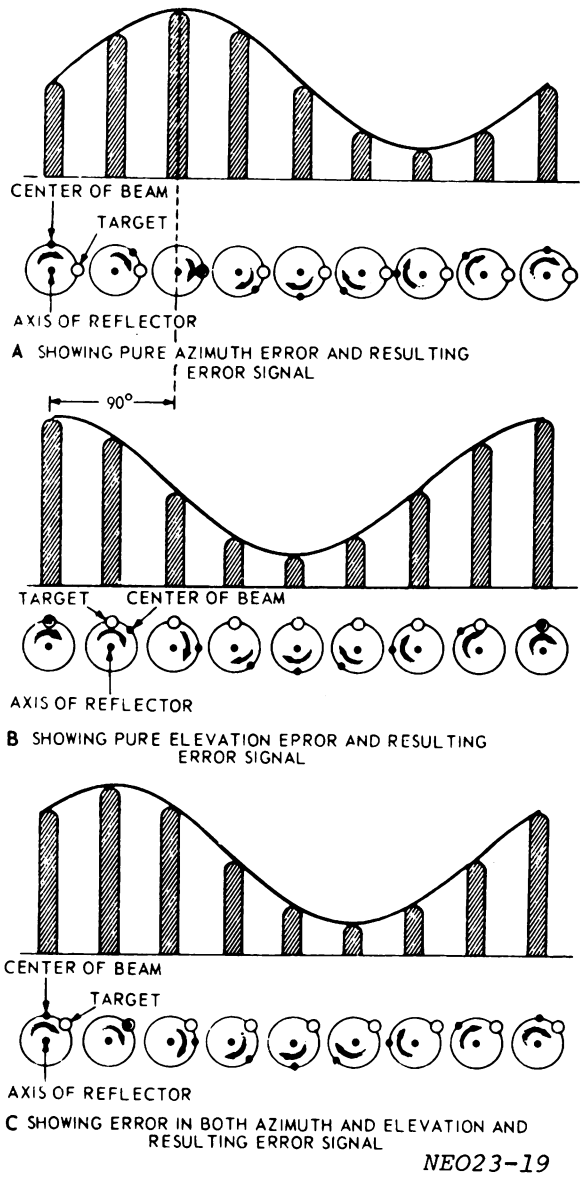

Figure 5-8. Signals produced by pointing error.

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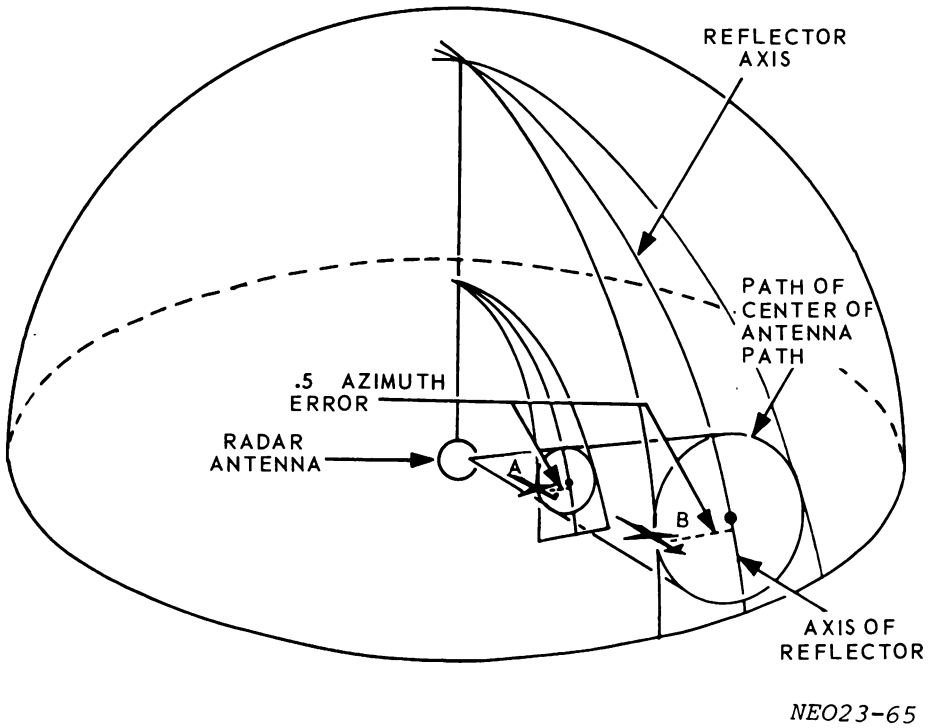

Figure 5-9. Phase correction.

output signals from the balanced amplifier are amplified 30-Hz sine waves which are fed to the commutator tubes in the azimuth and elevation tracking unit.

Power supply. The power supply furnishes +105 volts regulated, +300 volts unregulated, and filament voltages.

Antenna Position Control Unit. The antenna may be positioned by the antenna control, by the PPI scan motor, or manually by means of the handwheels of the antenna position control unit. Since the azimuth and elevation circuits of the control unit are identical, only the azimuth channel is discussed. The PPI scan motor causes the stators of the azimuth and elevation control selsyns to rotate in the PPI mode of operation. The rotor of the elevation selsyn turns only enough to tilt the antenna through a 20° vertical sector.

Control selsyns. The azimuth control selsyn and the elevation control selsyn transmit error signals to the selsyn transformers in the pedestal. The stators of the selsyns may be rotated manually be the two handwheels in the manual mode of operation. In PPI scan mode, the selsyn stators are turned by the PPI scan motor.

Followup motors. The azimuth and elevation followup motors keep the control selsyns aligned with the selsyn transformers when the radar set is tracking automatically. In automatic operation, the control selsyns are not used. Therefore, if the selsyns are not kept in alignment with the antenna, the antenna slews violently when the set is taken from an auto-angle mode to any other mode. To prevent this, the followup motors react to the signals produced by the selsyn transformers and turn the control selsyn rotors to reduce the error signal to zero.

Antenna Control (Sector Scan Unit). The sector scan unit accepts the selsyn error signal in a sector scan mode and uses it to control the antenna. This mode action is a specialized form of manual antenna operation. The azimuth handwheels can still position the antenna, but when they are untouched, the antenna scans a sector about the original position. The elevation selsyn system operates in the normal manual procedure. The sector scan relay is operated by the sector scan mode button, and switches in the sector scan unit or bypasses it as shown. The output of the sector scan unit is fed to T401 and from there to the azimuth and elevation tracking unit.

Nutating Drive Motor and Reference Generator. The nutating drive (spinner) motor turns the reference generator armature and causes the dipole to nutate at 1800 rpm. The reference generator produces two 30-Hz voltages 90° out of phase which are used for automatic tracking.

Phaser. The phaser section provides corrections for aircraft returns where aircraft are at high elevation angles or at long ranges.

Phase corrector. The outputs from the reference generator are fed through the phase corrector and then applied to the azimuth and elevation tracking unit. The phase corrector compensates for phase shifts in the returned signal due to range by shifting the reference voltages accordingly.

Secant corrector. Mounted in the same unit as the phase corrector is the secant corrector. For aircraft at different elevation angles, the amount of returned

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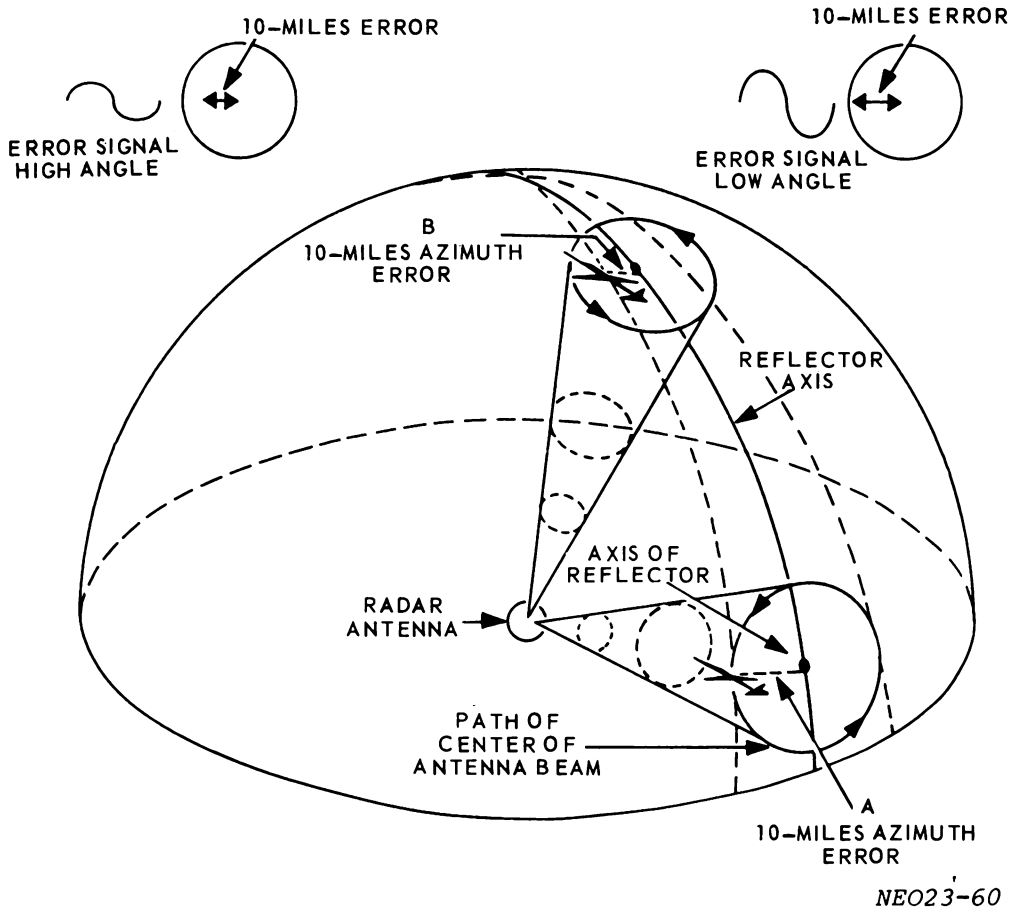

Figure 5-10. Secant correction.

signal amplitude will be different (see fig. 5-10). Although the degree of azimuth error is the same, the horizontal range of the aircraft from the reflector axis is different. Hence, for high elevation angles, the gain of the azimuth channel is increased.

Azimuth and Elevation Track Unit. This unit receives the error signals and reference voltages. When tracking automatically, the error signals are produced by the automatic tracking unit and the reference voltages are supplied by the reference generator. If the radar set is tracking in one of the MANUAL positions, the reference voltages are supplied by the 60-Hz AC line and the error voltages are produced by the selsyn transformers. The output of the azimuth and elevation tracking unit is a DC which is proportional to the error voltage.

Squarer circuits. When the set is tracking automatically, the contacts of the manual-automatic relays are in the AUTOMATIC position and the two 30-Hz reference voltages from the phase corrector are fed to the grids of the azimuth and elevation squarer tubes. During operation in any of the manual modes, the contacts of the manual-automatic relays are in the MANUAL position and the 60-Hz reference voltage is fed to the grids of the squarer tubes. In all types of operation, the outputs are square waves 180° out of phase. These are used for plate voltage in the commutator circuits.

Commutator circuits. In addition to the square-wave voltage from the squares, these two commutator circuits (azimuth and elevation) receive the error voltages which are fed to the grids from either the automatic tracking unit or the selsyn transformers. The outputs of the commutator circuits are two DC voltages taken from the cathodes. As long as the antenna is on target, the cathode voltage remains at +76 volts. As the antenna varies off target, the cathode voltage varies above or below +76 volts, depending upon the amount and direction of the error.

DC amplifiers. The output voltages of the commutator tubes are fed directly to the grids of the DC amplifiers (azimuth and elevation) through a filter circuit. As long as the input voltage remains at +76 volts, a constant plate current flows through the DC amplifiers. When the input voltage to the amplifiers changes, the plate current changes a proportional amount. The plate load for the DC amplifiers is the field winding of one of the amplidynes in the servosystem.

Antihunt circuits. The antihunt circuits prevent the antenna from hunting or oscillating about the point of zero error voltage output. As the antenna reaches this

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point, its inertia causes it to pass the point and an error of opposite polarity is produced. The antenna then reverses and overshoots in the opposite direction. Thus, the antenna oscillates or hunts about the point of zero error voltage. To dampen the oscillations, a signal is fed back to the screen grids of the DC amplifiers from the drive motors of the servosystem. This opposes any change in armature current and brings the antenna quickly to a stop.

Torque-limiting circuits. These two circuits (azimuth and elevation) reduce the grid voltage of the DC amplifiers if the error signal becomes great enough to move the antenna at an excessive rate. The plates of the torque limiter tubes are connected to the control grids of the DC amplifiers. When the current to the drive motor becomes excessive, the torque limiter tubes conduct and the drop in plate voltage is applied to the control grids of the DC amplifiers.

Servosystem. The servosystem contains the drive motors that cause the antenna to rotate in azimuth and to tilt in elevation. This system also contains the amplidynes which produce power for the drive motors.

Amplidynes. The amplidynes or motor-generators, which consist of an AC motor and a DC generator, amplify the error signals and apply them to the armatures of the drive motors.

Drive motors. The azimuth and elevation drive motors supply the mechanical power to turn the antenna. The outputs of the amplidynes determine the speed and direction of the desired rotation. Outputs are fed to the antihunt and torque-limiting circuits in the azimuth and elevation tracking unit.

Azimuth and Elevation Indicator. This unit contains the local-remote relays. When these relays switch to the remote position, they connect the selsyn transformers to the input from the remote unit instead of the input from the control selsyns in the radar set. The indicator unit displays the position of the antenna by means of synchro-operated dials. The unit contains four receiving selsyns which are geared to concentric pointers on the two indicator dials. The circular scales of the indicating dials are marked with degrees; the azimuth dial reads from 0° to 359° and the elevation dial from -10° to 90°.

Exercise (472):

1. Match the terms in column A with the appropriate purposes in column B by writing the correct letter in the blank provided. Each purpose may be used once or not at all.

Column A	*Column B*
____ 1. Automatic tracking unit.	a. Determine the speed and direction of the desired rotation.
____ 2. Antenna position control unit.	b. Produces an error voltage when the radar is tracking automatically.
____ 3. Sector scan unit.	c. Positions the antenna in all modes of operation *except* automatic.
____ 4. Nutating drive motor and reference generator.	d. Provides correction for targets when the targets are at high elevations or long ranges.
____ 5. Phaser.	e. Causes the antenna to search an area about the original position.
____ 6. Azimuth and elevation tracking unit.	f. Produces a DC output which is proportional to the error voltage to drive the servosystem.
____ 7. Azimuth and elevation indicators.	g. Shows the position of the antenna by means of synchro-operated dials.
____ 8. Servosystem.	h. Produces two 30-Hz signals 90° out of phase for automatic tracking.
	i. Provides correction for targets when the targets are at low elevations or long ranges.
	j. Produces two 30-Hz signals 180° out of phase for automatic tracking.
	k. Shows the position of the antenna by a visual display on a CRT.

473. List the alignments which must be verified before aligning the antenna-positioning system and explain why two people are required when performing some of the antenna-positioning system alignments.

Alignment. Prior to performing any of the antenna-positioning system alignments, the synchronizing system, transmitting system, and receiving system must be properly aligned. This is to insure that all errors existing in the circuits which feed the antenna-positioning system have been eliminated. The units within the system are aligned individually according to the applicable technical orders.

There are steps in the alignments requiring you to check circuitry mounted in the antenna pedestal. Extreme CAUTION and strict adherence to safety procedures are required. The technical orders state that two maintenance technicians are required to perform these alignments. You should verify the proper operation of the roof-mounted SAFETY-RUN switch before attempting any work on or around the pedestal. Also, the appropriate warning sign *must* be displayed on the radar console. Finally, satisfy yourself that the man operating the console is well-versed in the alignment procedures and thoroughly briefed on the exact nature of the work you are going to perform within the pedestal.

Exercises (473):

1. List the alignments which must be verified prior to aligning the antenna-positioning system.

2. Why are two people needed to perform some of the antenna-positioning system alignments?

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CHAPTER 6

Presentation Systems

THE INFORMATION available from a radar receiver may contain as many as several million separate data per second. The presentation system is designed to display this data for use by the repairman or operator. An understanding of the fundamental characteristics of the presentation system will enable you to maintain and operate the radar more efficiently.

6-1. Cathode-Ray Tubes

The indicator systems of any radar must be able to present a continuous, easily understandable picture of all radar targets which intercept the transmitted RF beam. A cathode-ray tube (CRT) very satisfactorily fulfills these requirements. Since a cathode-ray tube is unable to present a three-dimensional picture (except for very limited applications), more than one CRT is usually used in any radar indicator system.

The picture seen on the screen of a CRT is called the *display,* the *indication,* or the *presentation.* The tube itself is referred to as the *indicator, CRT,* or *scope.*

Often, when a CRT presenting a particular form of display is to be identified, a descriptive adjective or code designation is prefixed to the term "scope." These prefixes are often extended to include devices and circuits auxiliary to the CRT proper.

474. List the two types of cathode-ray tubes used in autotrack radar systems and explain the difference between them.

Two types of CRTs are commonly used in autotrack radar indicator systems: the electrostatic and electromagnetic types. This does not mean these are the only type CRTs available. New CRT designs make use of a combined electrostatic-electromagnetic type of tube. Since our concern is centered in the individual electrostatic and electromagnetic types, we will confine our discussion to these.

Electrostatic CRTs. Figure 6-1 shows the elements contained within the glass envelope of an electrostatic CRT. This type of tube uses an electron gun which

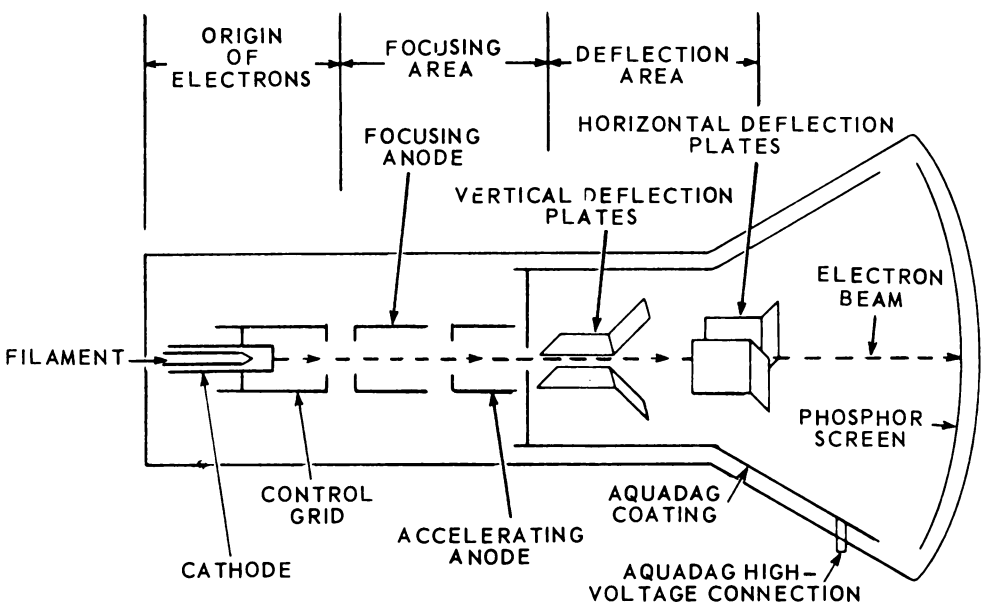

Figure 6-1. Electrostatic CRT.

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includes focusing electrodes, the emitter and control grid, a means for accelerating the electron beam on its way to the CRT screen, and the horizontal and vertical deflection plates. The deflection system uses two sets of plates, located back of the phosphor screen and positioned at right angles to one another.

The accelerating anode is a basic element of the electron gun. An aperture in the control grid permits electrons to move from the cathode toward the CRT screen along the axis of the electron gun. This element controls the density of the electron beam and also functions as part of the initial focusing element. The electron beam next passes through an electrostatic field which exists between the control grid and the focusing anode.

Once the electrons have passed through the aperture of the control grid, and while they are still in the electrostatic focusing field, a voltage on the accelerating anode increases the electron beam velocity. After leaving the focusing area, the electron beam passes through the deflection area and strikes the screen to form a visible spot. The voltages at the deflection plates are of such polarities as to develop continuous push-pull action to cause the electron beam to be attracted toward one plate and repelled from the other plate, thereby forming the sweep.

Electromagnetic CRTs. Figure 6-2 shows the elements contained within the glass envelope of an electromagnetic CRT. As shown, the primary differences between the two types of CRTs are the replacement of the focusing anode and deflection plates with focus coils and deflection coils.

Electron beam focusing. The axis of the magnetic field generated by the CRT focus coil parallels the Z-axis (the axis perpendicular to the X- and Y-axes) of the tube. The electrons contained in the electron beam enter the focusing field with diverging paths. Since the axial length of the field is short while the velocity of the electrons is high, the electron paths are affected for only a short time by the magnetic field lines of force. As a result, the deflecting force is limited, and the individual electrons complete only a portion of the helical turn while in the limits of the field. This portion of a turn is sufficient to change the electron paths from divergent when they enter the magnetic field to convergent on leaving the field.

This is the basic principle of how the focus coil's magnetic field controls the paths of the electrons comprising the electron beam. Increasing the strength of the focus field causes each electron to travel through a greater portion of a helical turn within the field. Thus, the electrons converge at a point closer to the magnetic field. While in the field, the electrons follow a curved path because of the influence of the field. However, after leaving the field, the electrons follow a straight path until they strike the CRT screen.

Electron beam deflection. The point at which the electrons strike the CRT screen depends on the angle of electron beam deflection and the distance between the center of the magnetic field and the CRT screen. The distance is determined by the tube manufacturer and remains a constant factor in each tube. Thus, the point at which the electron beam hits the CRT screen depends on two principal factors which we are able to

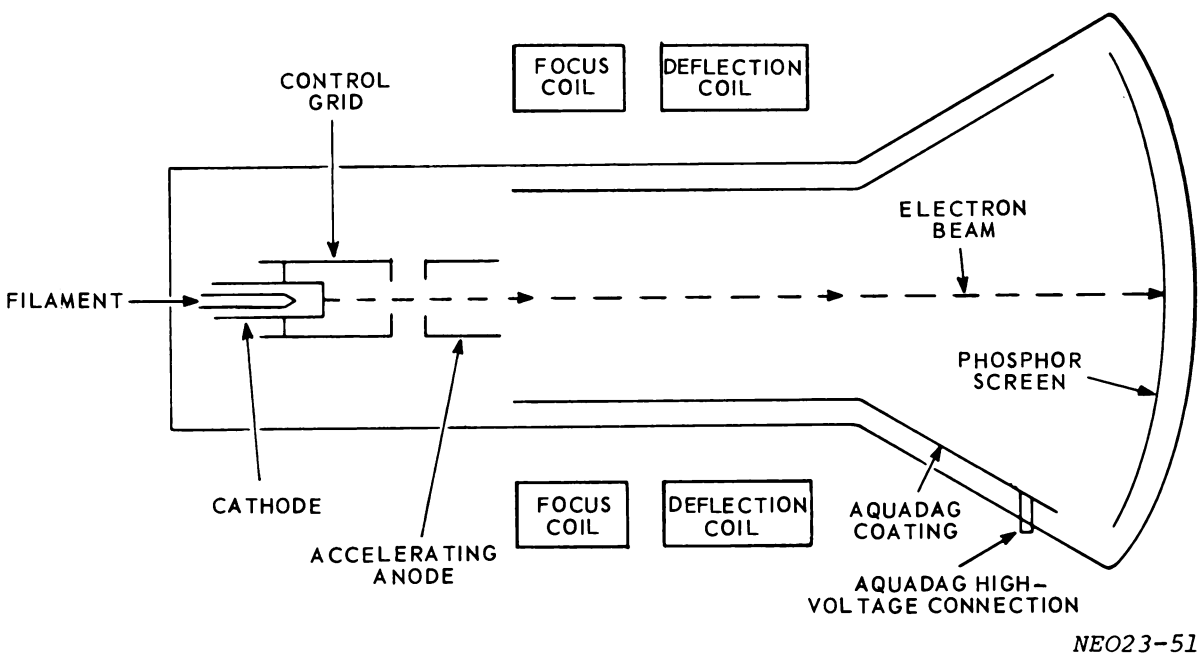

Figure 6-2. Electromagnetic CRT.

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control: the velocity of the electrons and the strength of the field. An increase in electron velocity, or a decrease in field strength, causes a smaller angle of deflection.

The electron beam may be deflected by using rotating deflection coils or fixed deflection yokes. If rotating deflection coils are used, two coils are placed opposite each other across the neck of the CRT. The coils are connected in series, and each coil generates a magnetic field proportional to the current flow through it. If current flow is increased at a linear rate from a zero reference point, an electron beam scan from the center of the CRT screen to the outside edge will be seen. The direction of the beam is controlled by rotating the coils about the neck of the CRT, which, in turn, changes the direction in which the magnetic field is active.

Fixed deflection yokes make use of the same magnetic principle. However, with this type of deflection arrangement, two sets of coil windings are positioned at right angles to one another. This arrangement causes one set of windings to generate a magnetic field at right angles to the field generated by the other set of windings. Since the lines of force from the two fields cannot cross each other, only a single resultant field exists within the yoke. The direction of action and the intensity of this resultant field are determined by the directions of the two originating fields and their relative intensities. If the fields are increased in intensity at equal rates, the resultant field is at a 45° angle to the two originating fields.

In these two types of deflection arrangements, current flow is always in the same direction through the coil windings. Push-pull operation may be derived by simply placing two windings, wound in the same direction, on each leg of the yoke. Since the windings are wound in the same direction, their currents flow in opposite directions (because of the windings' input connections), and the magnetic fields generated by the two windings are in opposite directions. When current flow in each winding is equal, the two fields are equal and opposite and therefore cancel.

Exercises (474):

1. What are the two types of cathode-ray tubes used in autotrack radar systems?

2. What is the primary difference between the two types of cathode-ray tubes?

3. How is the electron beam focused in the electromagnetic CRT?

4. How is the electron beam deflected in the electromagnetic CRT?

6-2. Indicators

The radar indicator displays expressed in quantities that we are concerned with are azimuth, elevation, and range. These quantities always relate the position of a target to the origin at the radar antenna. We will concern ourselves mainly with range displays in this chapter. Azimuth and elevation displays will be discussed in more detail later in the volume.

Range is the coordinate that is most often duplicated when more than one type of radar display is used. In autotrack radars, range is displayed on either A-scopes, B-scopes, or J-scopes.

475. Draw the scan of an A-scope and describe how the sweep is generated and video displayed.

A-Scope. Figure 6-3 shows the scan of an A-scope. If the sweep represents the total radar range, as shown in the figure, the sweep baseline starts at the instant a pulse of energy is radiated by the antenna and travels at a constant velocity across the CRT screen. When the baseline reaches the right side of the screen, it is blanked out, jumps quickly back to the left side, and the sweep cycle is repeated. Receiver video pulses cause a vertical deflection of the baseline which is proportional to the strength of the video pulse.

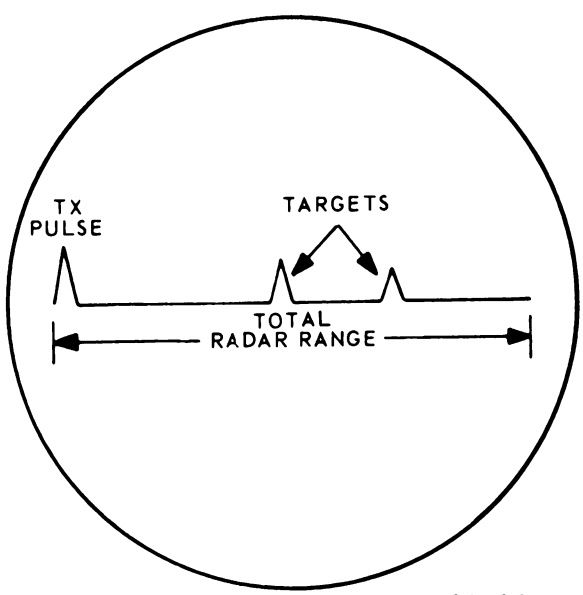

Figure 6-3. A-scope scan.

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Some range sweeps do not represent the total radar range but only an expanded portion. For instance, one of our systems uses three A-scopes as range indicators. One indicator represents the total radar range and has a referenced sweep. Another sweep represents an expanded 32,000-yard portion of the overall range, and the remaining indicator a 2000-yard expanded portion of the 32,000-yard sweep. Both of these sweeps are phased. The time at which these two sweep gates occur is determined by the setting of the range computer. In all cases, various markers are superimposed on the sweep baseline to indicate what expanded portion of the overall range we are expanding, and the position where the video must appear on the sweep before we can initiate automatic range tracking.

Sweep baseline is formed by simultaneously applying sawtooth voltages (180° out of phase with one another) to the horizontal deflection plates. A negative-going sawtooth is applied to the left deflection plate and simultaneously a positive-going sawtooth is applied to the right deflection plate. The baseline is thus formed by the electron beam's being forced to move to the right.

Vertical deflection for an A-scan indicator is accomplished by simultaneously applying positive video pulses to the top vertical deflection plate and negative video pulses to the bottom vertical deflection plate. Again, the positive pulse attracts the electron beam, and the negative pulse repels it. Therefore, a vertical deflection of the sweep occurs when the video pulses are present.

Exercises (475):

1. Draw the scan of an A-scope.

2. How is the sweep generated?

3. How is the video displayed?

476. Draw the scan of a B-scope and describe the relationship of the range and angle sweeps.

B-Scope. Figure 6-4 shows the scan of a B-scope. A B-scope indicator presents range and angle information. The B-scope presents the TX pulse and the returned signals as bright spots (blips) on the time baseline. The time base itself moves across the screen, synchronized with the RF beam motion. The scanning spot moves from the bottom to the top of the screen, each vertical line being synchronized with a transmitted pulse for an indication of range. At the same time, due to the RF beam rotation, the sweep itself is slowly moved horizontally across the screen. The height of the spot above the baseline indicates the range or distance of the target. The centerline (marked zero degrees) of the screen indicates the antenna azimuth angle.

The B-scope is used with TWS autotrack radar. In this case, the centerline (boresight) represents the azimuth angle of the antenna, and if the target is to the right or left of the centerline, it represents how many degrees must be added or subtracted from the antenna azimuth angle to arrive at the target's azimuth range. For example, let's assume the antenna azimuth angle is at 45° and the target on the scope is at +10°; then the target azimuth is 45° + 10° = 55°.

Exercises (476):

1. Draw the scan of a B-scope.

2. What is the relationship of the range and angle sweeps on the B-scope?

3. How is range and angle information determined on a B-scope (refer to fig. 6-4)?

477. Draw the scan of a J-scope and describe how the sweep is generated and video displayed.

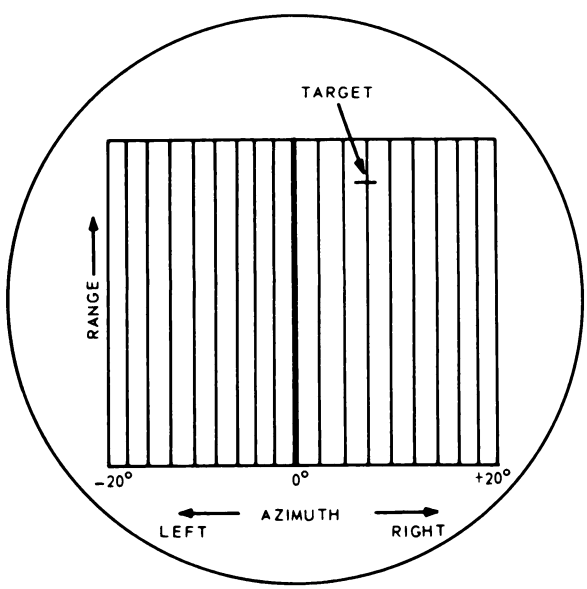

Figure 6-4. B-scope scan.

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J-Scope. Figure 6-5 shows the scan of a J-scope. The J-scan is nothing more than a modified A-scan. Instead of the sweep scanning from left to right in a straight-line path, the sweep is curved to scan in a circular path near the outside edge of the CRT screen. In systems using J-scopes for range presentation, three indicators are also used. One indicator represents the total radar range, and its sweep is phased. In this indicator, trigger phasing is used; the start of this particular indicator sweep always coincides with the trigger. The second scope represents a 40,000-yard expanded portion of the overall radar range. The remaining scope represents a 2000-yard expanded portion of the 40,000-yard sweep. Both of the scope sweeps are referenced, and the time at which they occur depends on the setting of the range computer.

The sweep baseline for the J-scan is accomplished by using sine-wave voltages. The deflection voltages applied to the horizontal deflection plates are 180° out of phase with one another. The deflection voltages applied to the vertical deflection plates are also 180° out of phase with one another and 90° out of phase with the horizontal deflection voltages. This causes the electron beam to scan the CRT screen in a circular pattern.

Video deflection for a J-scope is accomplished by using an anode which is located in the exact center of the CRT screen. Negative video pulses are applied to the anode, causing the sweep to deflect outward when a video signal is present.

Exercises (477):

1. Draw the scan of a J-scope.

2. How is the sweep generated?

3. How is the video displayed?

478. List the displays used, their inputs, and the origin of the inputs in systems employing J-scopes.

In autotrack radar systems using J-scan range indicators, three displays are used: a 400,000-yard display, a 40,000-yard display, and a 2000-yard display. Since the sweep stages associated with each scope are very similar, only the 400,000-yard sweep stages are shown in detail.

In this type of indicator, external sources furnish all of the sweep drive voltages, unblanking gates, and the various display markers. The inputs and their origins are:

a. IF input—This input is received directly from the receiver IF stages. It is transformed into video and applied to the center mode of all three scopes.

b. 410-Hz sweep drive—This input is a phased output of the synchronizer and is used to drive the 400,000-yard sweep.

c. 4100-Hz sweep drive—This input is a referenced output of the synchronizer and is used to drive the 40,000-yard sweep.

d. 40,000-yard unblanking gate—This input, the width of which is variable, is a referenced output of the synchronizer and is adjusted to unblank the 40,000-yard sweep for approximately 32,000 yards.

e. Track gate—This input is a referenced output of the synchronizer and is positioned in the center of the 40,000-yard sweep.

f. 2000-yard unblanking gate—This input, the width of which is variable, is a referenced output of the synchronizer and is adjusted to unblank the 2000-yard sweep for approximately 1500 yards.

g. N^2 gate—This input is a referenced output of the synchronizer and is positioned in the center of the 2000-yard sweep.

h. 82-kHz sweep drive—This input is a referenced output of the synchronizer and is used to drive the 2000-yard sweep.

All of these inputs and their related time positions can be seen by referring to FO 1.

As you have noticed, the sweep drive inputs are of different frequencies. Mathematically, it can be shown that one full cycle at 82 kHz equals 12.2 μsec, or 2000 yards; one full cycle at 4100 Hz equals 244 μsec, or 40,000 yards; and one full cycle at 410 Hz equals 2440 μsec, or 400,000 yards. The sweep drive frequencies thereby match the sweep distance we wish to display.

NOTE: These figures do not match the widths of the unblanking gates because the full circle sweep is not

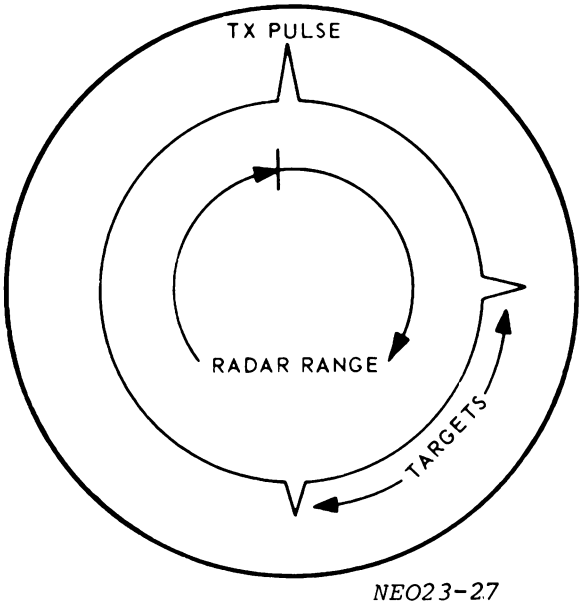

Figure 6-5. J-scope scan.

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present on the 2000-yard and 40,000-yard scope. Rather, a small portion (500 yards of the 2000-yard sweep and 8000 yards of the 40,000-yard sweep) remains blanked at all times. The 400,000-yard scope contains a complete circular sweep, since its sweep drive frequency is the same as the radar trigger PRF and a complete sweep is required to present a full-range display.

Now let's finish this discussion by going through the sweep circuit for the 400,000-yard indicator, which is diagrammed in figure 6-6. The 410-Hz sweep drive voltage is applied to a frequency-selective feedback amplifier. The 410-Hz amplified sine wave then passes through two additional amplifier stages and is applied to the horizontal sweep transformer T1. The outputs of T1, taken from opposite ends of the secondary winding, are two 410-Hz sine-wave voltages 180° out of phase with one another. These two voltages are applied to the horizontal deflection plates of the 400,000-yard indicator. Connected to one end of the secondary winding of T1 is a phase-shift network. The voltage applied to the network is phase-shifted 90° and applied to the vertical output amplifier. The voltage is amplified, sent to the vertical sweep transformer, and two voltages 180° out of phase with one another appear at the opposite ends of the secondary winding. These voltages are applied to the vertical deflection plates of the 400,000-yard indicator. Thus, the voltages present at the horizontal deflection plates are 180° out of phase with one another and 90° out of phase with the voltages present at the vertical deflection plates. In this way, a circular sweep pattern is obtained on the CRT screen.

Exercises (478):

1. What displays are used in systems employing J-scopes?

2. List the inputs and their origin.

479. Draw the scan of a plan-position indicator (PPI) scope and state how the sweep is generated and moved.

PPI Scope. The PPI is the most widely used and versatile of all radar displays. The origin of the PPI sweep (the radar) is usually located in the center of

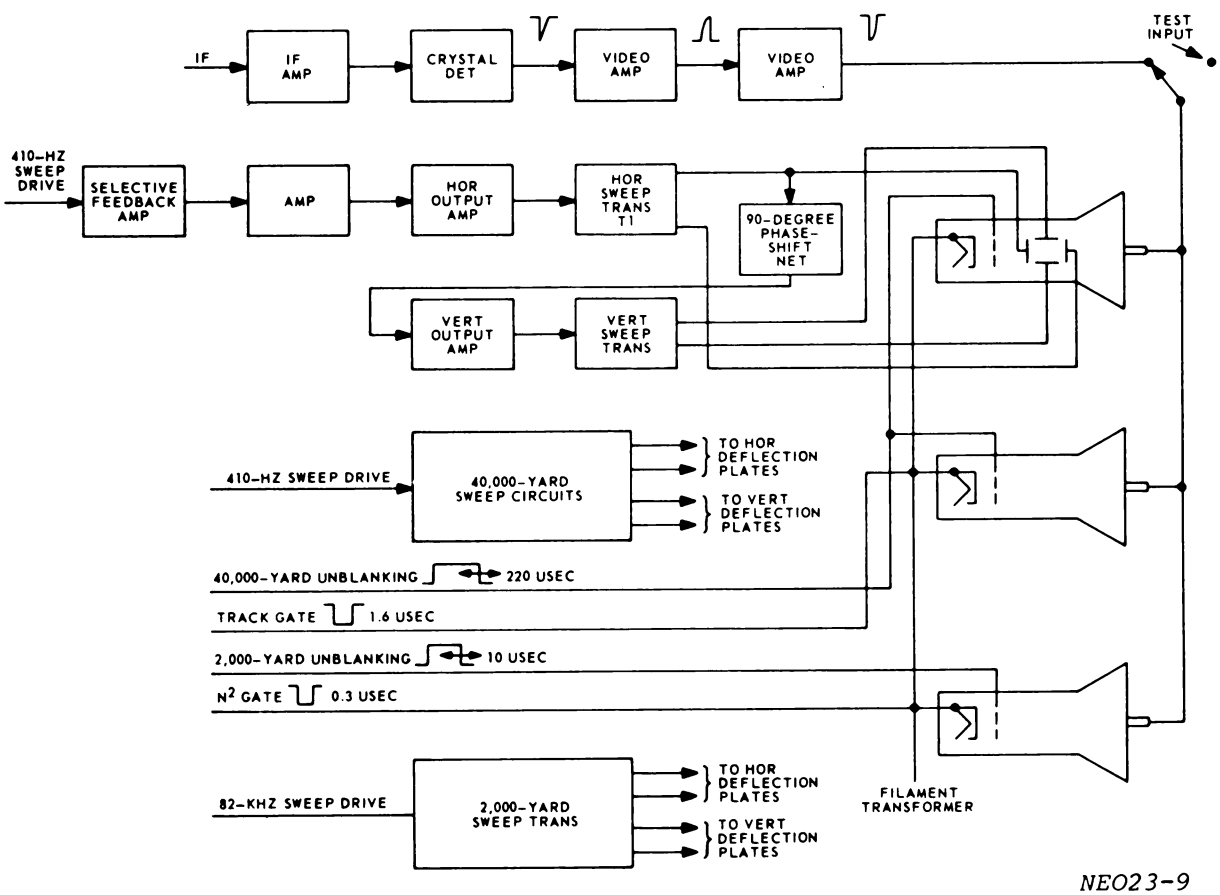

Figure 6-6. J-scan indicator system.

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the PPI screen and therefore provides an equal field of view in all directions. Sweep scan is accomplished by rotating a range sweep about the sweep axis in synchronization with the azimuth scanning of the antenna.

Figure 6-7 shows the PPI scan. The range sweep is the result of the conventional linear sawtooth voltage previously discussed.

Sweep scanning is accomplished by using either a modulated carrier transmitted from an antenna synchro to the PPI sweep circuits or by feeding the range sweep (sawtooth) into an antenna synchro and then to the PPI deflection coils. In either case, the PPI sweep position always represents the azimuth position of the radar antenna.

Exercises (479):

1. Draw the scan of a PPI scope.

2. How is the sweep generated?

3. How is the sweep moved?

480. Given a list of circuits within the plan-position indicator (PPI), identify the function of each circuit.

The following discussion, together with the block diagram (see fig. 6-8), explains the part each stage of the PPI system plays in producing the map on the PPI scope.

Sweep generation and positioning. A PPI system requires a sweep which always starts from the same place, in step with the transmitter burst, and moves at a fixed rate which has a relation to range. This sweep must also rotate, in step with antenna rotation, to indicate azimuth information. The circuits which do these jobs will be considered first.

- Trigger amplifier (V1614A and V1614B). The sweep on the PPI scope must be synchronized with the firing of the transmitter. Therefore, the synchronizer applies a trigger to the PPI unit and the transmitter simultaneously. The PPI trigger is fed to V1614A, then to V1614B, two stages of trigger amplification. Each section amplifies and inverts the input trigger pulse.
- Multivibrator (V1603). The amplified negative trigger pulse is fed to a multivibrator, V1603. This multivibrator has a rectangular wave output whose leading edge is synchronized with the transmitter output. With the RANGE SELECTOR switch S1601 (not shown in fig. 6-8), in the 50,000-yard position, the output of V1603 is a rectangular wave which has a duration of 305 microseconds. When S1601 is in the 100,000-yard position, the width of the pulse is 610 microseconds. The output of the multivibrator in the 200,000-yard position of S1601 has a time duration of 1220 microseconds. The time duration of the multivibrator output determines the maximum range of the PPI system.
- Cathode follower (V1619A). The cathode-follower stage, V1619A, couples the multivibrator output to the range marker oscillator, the sweep intensifier, the clamper tubes, and the sawtooth generator. The cathode follower removes jitter from the trailing edge of the multivibrator output wave and allows the multivibrator to return quickly to its quiescent state.
- Sawtooth generator (V1602B). The sawtooth generator produces a sawtooth voltage which moves the beam across the PPI scope face. Its output starts at zero and rises at a constant rate to the value required to move the beam to the edge of the scope face. It is the movement of the beam which creates the sweep line. The length of time for which the sweep generator operates is determined by the duration of the multivibrator pulse which, in turn, is controlled by the setting of the RANGE SELECTOR switch, S1601. Switch S1601 also sets the rate at which the sawtooth voltage rises. The rate is set so that the final value of the sawtooth voltage is sufficient to deflect the sweep beam to the edge of the scope, regardless of the sweep duration.
- Selsyn driver (V1601). This stage is a power amplifier which drives, or excites, the rotor winding of the PPI selsyn in the antenna pedestal. The driver not only amplifies the sawtooth voltage but also modifies it to the trapezoidal form required to overcome the inductance of the selsyn windings.

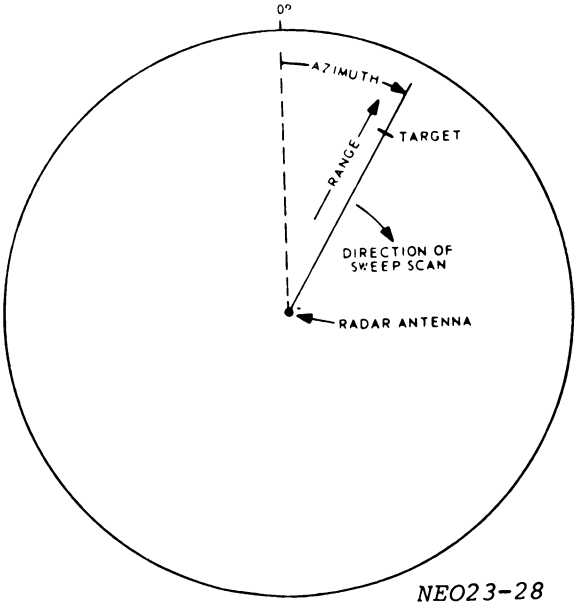

Figure 6-7. PPI-scan.

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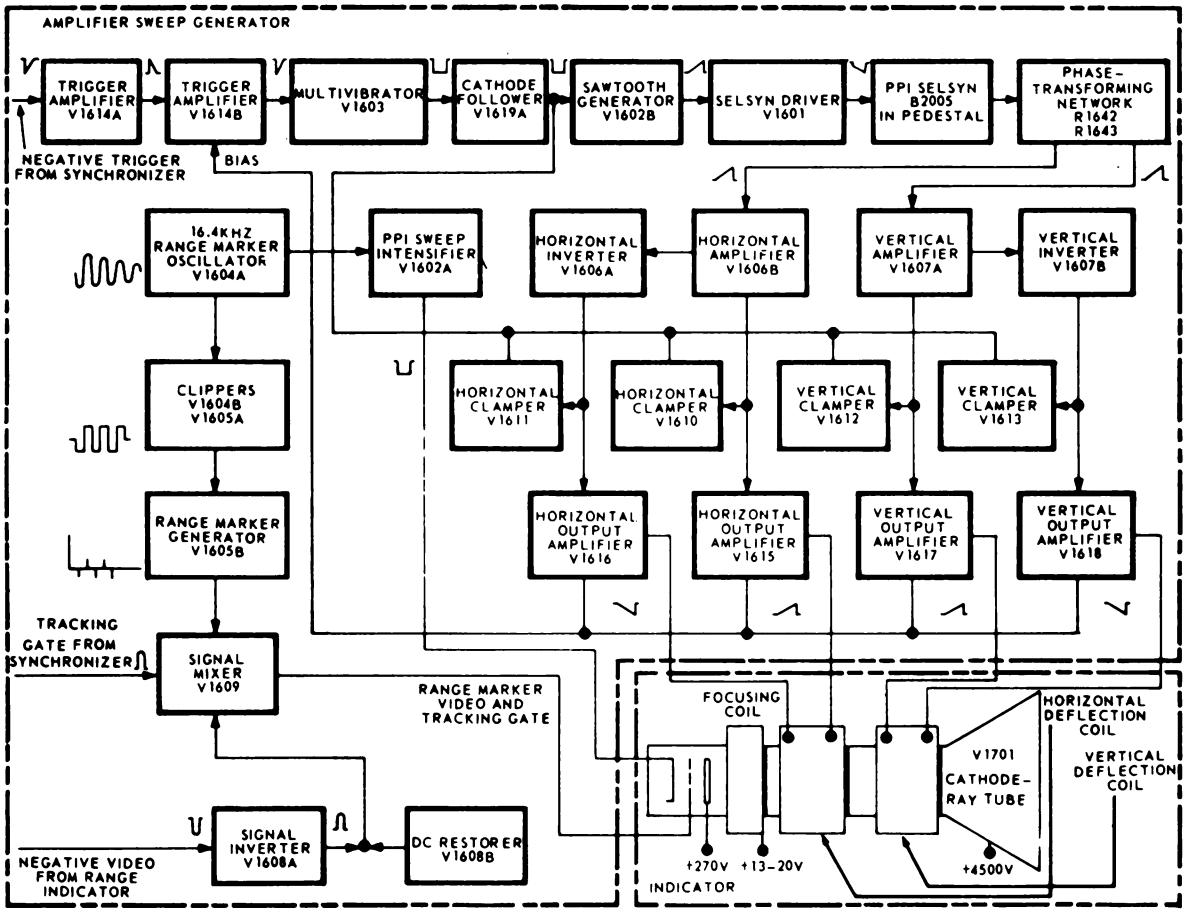

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Figure 6-8. PPI system block diagram.

• PPI selsyn (B2005). The PPI selsyn is geared to the antenna movement. Its rotor is geared to the antenna and completes one revolution for each revolution of the antenna. The selsyn acts like a transformer that has three secondary windings. The rotor is the primary and the three stator windings are the secondaries. The input voltage to the rotor is the trapezoidal wave from the selsyn driver tube. The voltage induced in each secondary winding depends upon the coupling between the winding and the rotor. As the antenna and the selsyn rotate, the voltage in each of the windings varies in amplitude in a sinusoidal manner. The outputs of the selsyn are three waves whose amplitudes are 120° out of phase.

• Conversion network. The PPI selsyn has three output voltages and the PPI scope has only two sets of deflection coils. The purpose of the conversion network is to convert the three selsyn outputs to two outputs whose amplitudes are 90° out of phase. These are needed to make the sweep line rotate in synchronization with the antenna. One of these outputs is maximum when the antenna points east or west. The other is at maximum when the antenna points directly north or south. Each sawtooth output forms a sine-wave envelope as the antenna rotates.

• Horizontal amplifier-inverters (V1606A and V1606B). The output of the conversion network is fed to the horizontal amplifier stage, which is immediately followed by an inverter stage. These stages produce two sawtooth voltages from the original input. Each wave is of equal amplitude but opposite polarity. One voltage starts at a fixed potential and rises; the other starts at the same fixed potential but decreases.

• Vertical amplifier-inverters (V1607A and V1607B). The vertical amplifier-inverter performs the same function as the horizontal amplifier and inverter. These stages produce two outputs of equal amplitude and opposite polarity from the input provided by the conversion network.

• Horizontal output amplifiers (V1615 and V1616). Each of the horizontal amplifier-inverter outputs is fed to separate horizontal output amplifiers which feed push-pull voltages to the horizontal deflection coil. When one winding is driven positive, the other winding is driven negative. This balanced deflection reduces sweep distortion.

• Vertical output amplifiers (V1617 and V1618). The vertical output amplifiers function in the same manner as the horizontal output amplifiers.

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• Clamping tubes (V1610 through V1613). The clamping tubes are used in the grid circuits of the output amplifiers to clamp the grids at a fixed potential between sweeps. This clamping action insures that all sweeps start from the center of the scope. The output of the multivibrator unclamps these tubes for the duration of the sweep and allows the output amplifiers to amplify the sweep.

Sweep intensifier (V1602A). The output of the multivibrator is fed to the sweep intensifier. This intensifier controls the bias of the PPI tube. The negative multivibrator pulse applied to V1602A lowers the bias on the PPI tube, thus allowing the tube to conduct for the duration of the pulse.

Range mark generation. Concentric circles are provided on the PPI display which indicate range. These circles may be spaced 10,000, 20,000 or 50,000 yards apart, depending on the setting of the RANGE SELECTOR switch.

• Range marker oscillator (V1605A). The range marker channel produces the signals which trace the range-indicating circles on the scope. The range marker oscillator produces clamped sine-wave oscillations at a frequency determined by the setting of the RANGE SELECTOR switch. The oscillator is shock-excited by the multivibrator output, which starts the oscillations at the same time as the scope sweep.

• Clippers (V1604B and V1605A). The output of the range mark oscillator is fed through two clipper stages which clip and amplify the positive and negative portion of the signals. As a result of this clipping, an almost flat-topped rectangular wave is obtained.

• Range marker generator (V1605B). The output of the second clipper is fed to the range mark generator, which produces sharp, positive pips that correspond to each of the negative-going sides of the rectangular input wave. These pips are fed through the signal mixer to the PPI scope and mark the range circles on the scope.

• Signal mixer (V1609). The signal mixer tube combines the range marker pulses and the track gate, feeding these signals to the PPI video amplifier.

PPI video amplifier. The PPI video amplifier (not shown in the block diagram) is a separate chassis which amplifies the video signals of all the received echoes, as well as the track gate and range markers from the signal mixer. After being amplified by the video amplifier, these signals are applied to the grid of the PPI tube.

Indicator (V1701). The electrons emitted by the cathode of the PPI tube are accelerated by two anodes and focused by a coil. The phosphorescent material on the face of the tube glows at the point where it is struck by the electron beam. The current through the focus coil is adjusted to produce a well-defined spot. The point at which the electron beam strikes the scope face is determined by the currents through the deflection coils. The sweep-generating circuits cause currents to flow through the coils deflecting the beam at a constant speed to the edge of the scope in the time equal to the duration of the multivibrator output. The direction in which the beam moves is determined by the relative amplitudes of the voltages applied to the horizontal and vertical deflection coils. These amplitudes are controlled by the position of the PPI selsyn so that the beam sweeps out according to the direction in which the antenna is pointing. As a result, the sweep line rotates when the antenna rotates.

Positive pulses representing target echoes, the track gate, and range markers are fed to the grid of the PPI tube. These pulses lower the tube bias. The number of electrons in the electron beam is increased, and the spot is produced by the brightening effect of the beam on the tube face.

Exercise (480):

1. Match the terms in column A with the appropriate functions in column B by writing the correct letter in the blank provided. Each function may be used once or not at all.

Column A	*Column B*
____ 1. Range mark generator.	a. Converts the three selsyn outputs to two signals whose amplitudes are 90° out of phase.
____ 2. Range mark clippers.	b. Produces three outputs that are 120° out of phase.
____ 3. Range mark oscillator.	c. Produces two outputs of equal amplitude and opposite polarity.
____ 4. Trigger amplifier.	d. Amplifies the sawtooth voltage and modifies it to a trapezoidal waveform.
____ 5. Multivibrator.	e. Amplifies and shapes the input trigger.
____ 6. Cathode follower.	f. Removes jitter from the trailing edge of the multivibrator output and permits the multivibrator to reset rapidly.
____ 7. Sawtooth generator.	g. Produces the voltage which moves the beam across the PPI scope face.
____ 8. Selsyn driver.	h. Produces a rectangular output whose leading edge is in sync with the trans- output.
____ 9. PPI selsyn.	i. Amplifies the sawtooths and feeds them to the deflection coils.
____ 10. Conversion networks.	j. Insures that the sweep starts at the center of the scope.
____ 11. Amplifier-inverter.	k. Controls the bias on the PPI tube during the negative portion of the multivibrator output wave.
____ 12. Output amplifier.	l. Produces sine-wave oscillations at a frequency determined by the setting of the RANGE SELECTOR switch.
____ 13. Clamping tube.	m. Produces sharp, positive pips that correspond to
____ 14. Sweep intensifier.	
____ 15. Signal mixer.	
____ 16. Video amplifier.	
____ 17. Indicator.	

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each of the negative-going sides of the rectangular input wave.

n. Changes the sine-wave input into an almost flat-topped rectangular wave.
o. Combines the range marks and track gate and feeds them to the video amplifier.
p. Provides amplification necessary to drive the indicator.
q. Provides a means of visually displaying the signals produced within the PPI.
r. Produces a fixed-radial line on the face of the scope.

6-3. Test Principles

The presentation system is provided primarily to furnish you with a visual display of the data acquired by the radar. Once acquisition and lock-on have been completed, the presentation system is desirable but not mandatory. Therefore, the presentation system alignments are flexible. You will align the system to suit your needs within the specification contained in the applicable technical orders.

481. List the units that must be aligned before aligning the indicators and state the need for precautionary measures during the indicator alignments.

Prior to aligning the presentation system, you should verify the alignments of certain other units. This is to be sure that all system errors are minimized and that you do not attempt to compensate for them on the visual display. The alignment of the synchronizer and range indicator power supplies, crystal oscillator, and frequency dividers should be performed or verified before aligning the indicators.

You should exercise extreme caution while performing the alignments of the presentation system. Each of the indicators contains a cathode-ray tube that is supplied with an aquadag voltage. This voltage is very high and can be lethal.

Exercises (481):

1. What alignment must be verified before performing the alignment of the presentation system?

2. Why should you be careful when performing the alignment?

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CHAPTER 7

Identification Equipment Systems

"NECESSITY IS THE mother of invention" is a cliché that was most true during World War II. With the invention of radar to detect aircraft, it also became necessary to differentiate friend from foe; thus, the invention of the identification system. The first type of identification, friend or foe (IFF) system was simple in principle of operation and served very well for many years. However, increases in aircraft traffic in addition to hot and cold war electronic countermeasures have made it necessary to produce more sophisticated IFF equipment. The selective identification feature (SIF) was developed to handle some of these problems. Since its advent, the SIF system has been refined, and its capabilities increased. It has been transistorized and microminiaturized, and is capable of numerous new automatic features—even to the point of an automatic visual and audible alarm to bring notice to PPI operators of an aircraft having an emergency condition.

7-1. The IFF/SIF System

The SIF system works on the two-way radio principle in that it requires two transmitters and two receivers to function. In other words, it does not rely on echos as does the radar. The SIF system consists of transponders installed in aircraft, a coder, an interrogator-responsor, decoders, and plan position indicators (PPIs) installed at radar sites.

In operation, interrogation pulses are developed by the coder unit to modulate the interrogator unit, with the resultant RF pulses being fed to a directional antenna that is constantly rotated through 360°. As the antenna is rotated, the transmitted RF pulses trigger the transponder of each aircraft that is located in the direction of the main beam and within the effective transmission range.

When the aircraft's transponder is triggered, it will transmit back coded reply pulses. The reply pulses are received by the receiver of the interrogator-responsor. The output video is routed to the decoders, which produce a single video pulse output for each coded pulse train reply. The time period from interrogator transmission until the reply is received from the aircraft's transponder determines the approximate range of the video indication on the PPI scope. The direction of the interrogator's antenna at the time of reply reception determines the direction (azimuth) of the aircraft from the radar site.

The structure of the pulse pair used for interrogation and reply provides individualized information pertaining to the responding aircraft.

482. Given a list of IFF/SIF units, identify the purpose of each.

Typical IFF/SIF Installation. A typical IFF/SIF installation is shown in figure 7-1. The following is a functional analysis of each component.

Coder-interrogator. The coder-interrogator produces the pulse pairs that code every interrogation. The coder-interrogator is controlled by a coder-decoder control unit, which is mounted at the operator's position in the radar set.

Pretriggers from the associated radar set are applied directly to the coder-interrogator but are delayed before being applied to the radar transmitter. This delay is necessary to compensate for the total delay of the IFF/SIF so that coincidence of the radar and IFF/SIF returns on the indicators can be obtained.

The triggers, which are applied to the coder-interrogator and cause it to initiate the mode output, encounter a countdown circuit which counts down the incoming triggers if the PRF is beyond the capabilities of the IFF/SIF system.

The coder-interrogator has three basic modes of interrogation (see fig. 7-2). Modes 1, 2, and 3 differ only in the spacing between their triggers. It is also capable of interlacing the three basic modes. For example, the first trigger can produce a Mode 1 output; and the next trigger, a Mode 3 output. Only two modes can be interlaced at any one time: Modes 1 and 3, Modes 1 and 2, or Modes 2 and 3. Interlacing allows an operator to simultaneously challenge more than one aircraft in different modes.

The coder-interrogator also sends the mode triggers to the video decoder to aid in determining if a correct code response has been received.

Radar recognition set and antenna transmits coded RF pulses within a frequency range of 990 to 1040 MHz at a minimum output power of 1500 watts. It receives signals from any aircraft equipped with the

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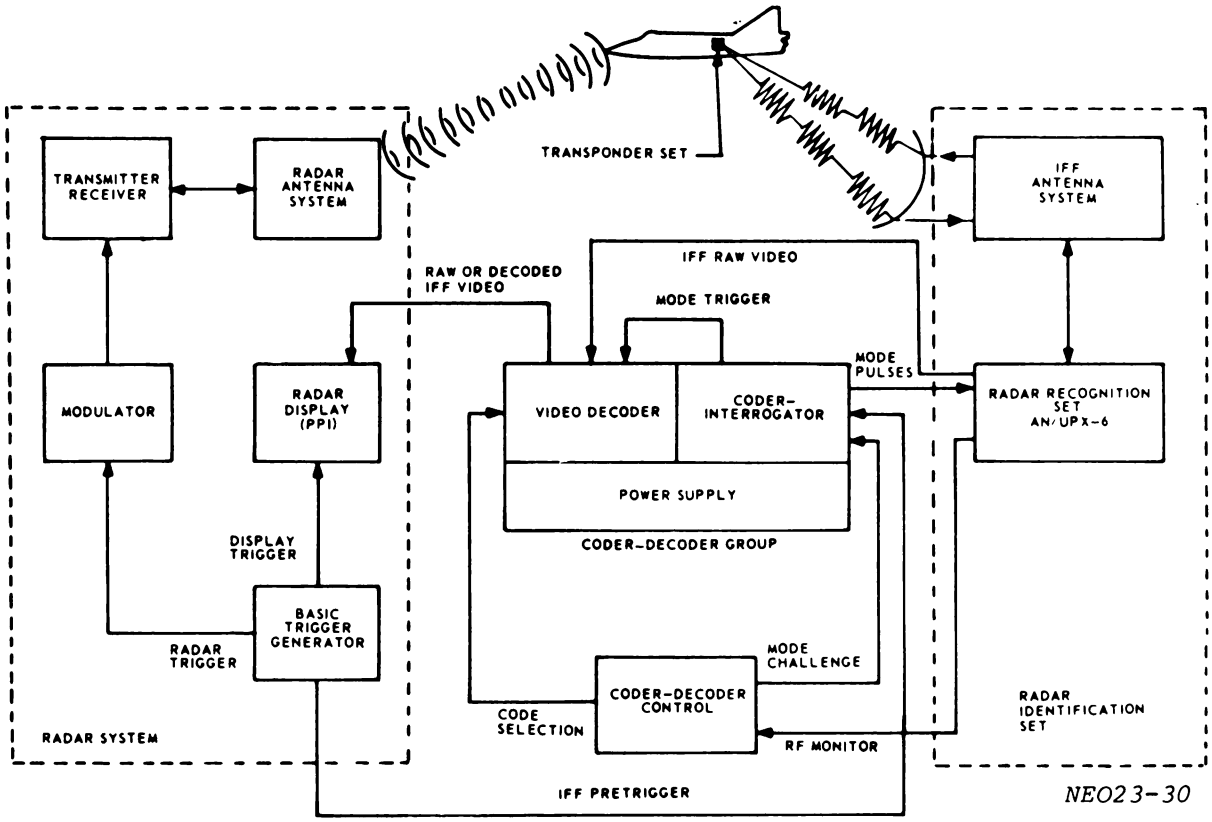

Figure 7-1. IFF/SIF system block diagram.

required transponder equipment within a frequency range of 1080 to 1130 MHz. These replies are detected and sent as video pulses to the video decoder.

Video decoder. The video decoder decodes the IFF decoder (SIF) code-train responses. The response information is compared with the interrogating mode triggers from the coder-interrogator and the mode-code input pulses. If the response is correct, a single pulse is developed and sent to the radar PPI. A provision is made where all received replies can be decoded. This is called raw or decoded IFF video. If the response is incorrect, no decoded output is produced.

Coder-decoder control. The coder-decoder control provides the operator with a means for selecting the interrogation modes and codes and for remotely controlling the radar recognition set. The control also provides the operator with a means for displaying several types of responses.

Power supply. The power supply is conventional and supplies all the various voltages required by the tube circuits in the coder-interrogator set. It also supplies all the smaller DC voltages needed by the transistor circuits in the remaining components.

The function of the associated radar is to provide the IFF/SIF pretrigger to synchronize the IFF/SIF system to the radar set.

Exercise (482):

1. Match the units in column A with the statement of the unit's purpose in column B. Some units may be used more than once.

Column A	*Column B*
____ 1. Radar recognition set and antenna.	a. Decodes the IFF/SIF code train responses.
____ 2. Coder-interrogation.	b. Selects the interrogation modes and codes.
____ 3. Radar system.	

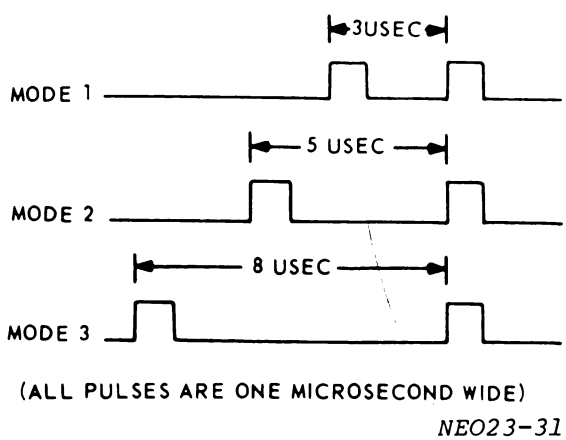

Figure 7-2. IFF interrogation coding.

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____ 4. Power supply.
____ 5. Video decoder.
____ 6. Coder-decoder control.

c. Provides IFF pretrigger.
d. Transmits and receives coded RF pulses.
e. Supplies the DC voltages.
f. Provides Modes 1, 2, and 3 pulse pairs.
g. Provides interlacing of Modes 1 and 3.
h. Counts down incoming triggers if the PRF is too high.

7-2. Principles of IFF/SIF Response Coding

Coding is one of the most useful features of IFF/SIF. This feature not only provides greater security but also aids in traffic control by allowing individual aircraft to distinguish themselves.

There are many different types of coding in IFF, but the most common one is multiple-space coding. In multiple-space coding, the interrogator transmits two RF pulses spaced several μsec apart. The aircraft transponder will respond if the pulse spacing is correct for its operational code. By varying the pulse spacing, we can have many codes.

483. Given selected model code trains, identify the code each represents.

Mode 1 Code. The complex code-train responses from the aircraft transponder consist of a series of pulses representing code intelligence. The intelligence is contained within a pair of bracket pulses spaced 20.3 μsec apart (between leading edges). The bracket pulses are an essential part of the response code and are always present. The other pulses making up the actual code are information pulses. There are many different combinations of information pulses that can be returned. Figure 7-3,B shows the bracket pulses, the information pulses, and the time relationship for each response code.

The time reference scale in figure 7-3,A shows the time relationship and pulse position, in any mode, for each code-train pulse. The upper numerals of the scale represent time intervals, and the lower numerals represent pulse positions.

The correct bracket pulse spacing, which is always 20.3 μsec between leading edges, is shown in figure 7-3,B. The bracket pulses are always located at pulse positions 1 and 15.

The Mode 1 code train, shown in figure 7-3,C, contains two bracket pulses and five information pulses. You will notice that the information pulses to the left of position 8 are designated "A." Each pulse

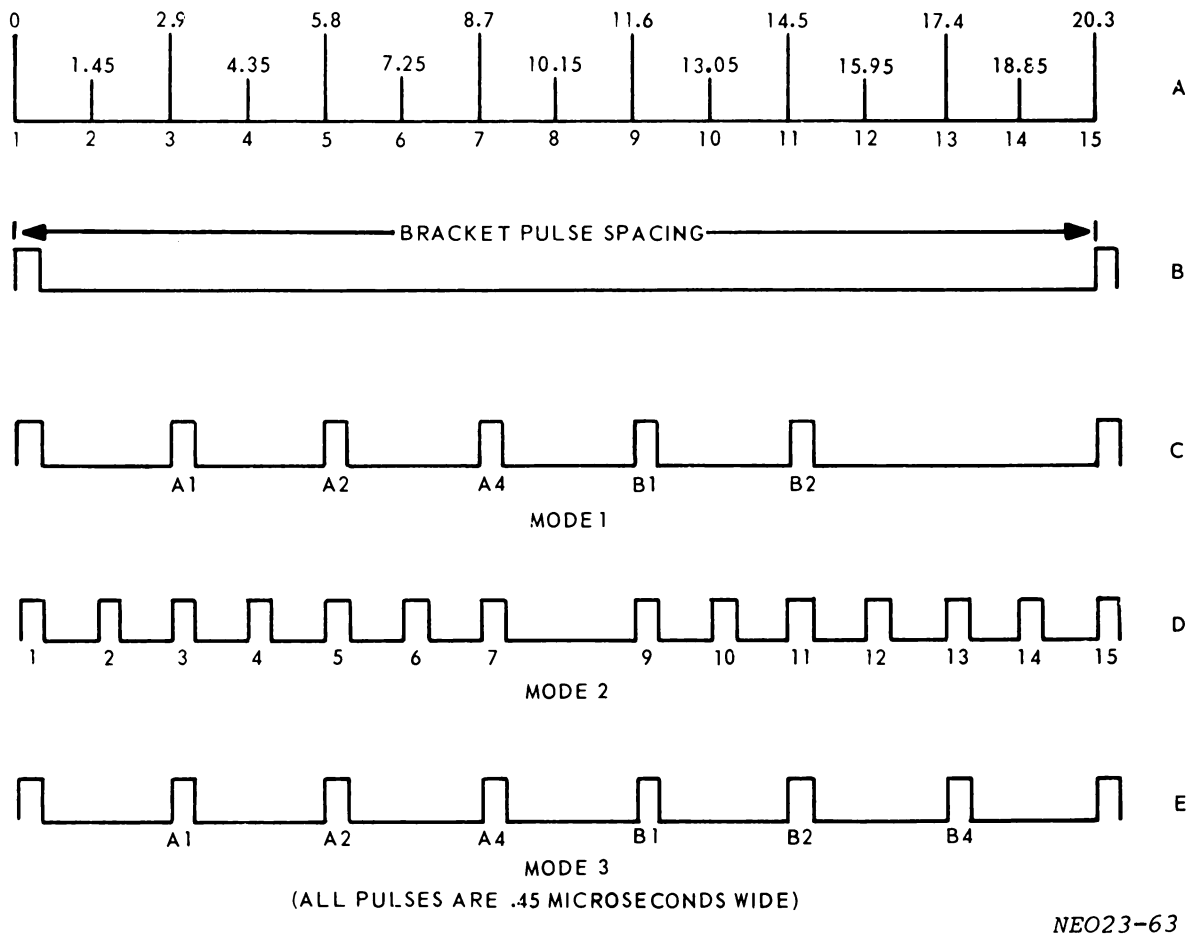

Figure 7-3. IFF/SIF response coding.

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has the numerical value of the number following the "A" or "B" designation.

All Mode 1 codes are in numerical form: code 70, code 02, code 23, etc. The left digit of the code is determined by adding the numerical value of the "A" pulses, and the right digit of the code is determined by adding the numerical value of the "B" pulses. If all of the "A" pulses are present in the Mode 1 code train, the left digit of the code is 7. If all of the "B" pulses are present in the Mode 1 code train, the right digit of the code is 3. Thus, with all the pulses present in the Mode 1 code train, the code is 73. Using various combinations of these five information pulses develops a total of 32 Mode 1 codes.

As an example, suppose a code train contained the two bracket pulses (which are always present) and the following information pulses: A1, A4, and B1. What code is represented by this code train? Adding the numerical value of the "A" pulses (1+4), we get 5 for the left digit. Since there is only one "B" pulse present and its numerical value is 1, the right digit of the code will be 1. Therefore, the code is 51. How can you determine which pulses are present in a code train representing code 03? First, the bracket pulses must be present. Since the left digit is 0, there are no "A" pulses. The "B" pulses, which must be present in order to give us 3, are pulses B1 and B2. The pulses representing code 03, therefore, are B1 and B2.

In normal operation, only 30 Mode 1 codes are used for identification purposes. Codes 73 and 00 are reserved for maintenance and tests. These two codes were selected for maintenance and tests because of their *all* or *none* pulse characteristics.

Mode 1 is the basic identification mode in IFF/SIF. All friendly aircraft, regardless of type or mission, will reply with the same Mode 1 code when they are interrogated. This code may be changed as often as necessary for security purposes.

Notice in figure 7-3, E, that the Mode 3 code train is very similar to the Mode 1 code train shown in figure 7-3,C. Because of this similarity, we will discuss Mode 3 before going through the operation of Mode 2.

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Exercises (483):
Refer to figure 7-4 to answer the following questions.

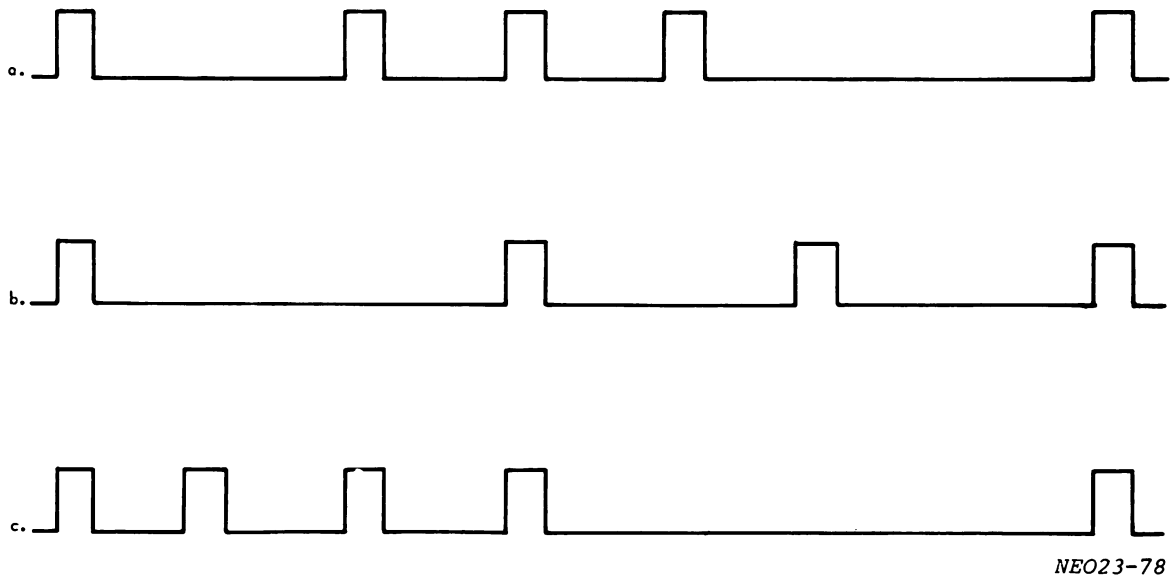

Figure 7-4. Response codes.

1. What is the code in part a?

2. What is the code in part b?

3. What is the code in part c?

484. Given selected Mode 3 codes, determine the pulse positions and draw the code train.

Mode 3 Code. The Mode 3 code train resembles a Mode 1 code train except that in Mode 3 the B–4 pulse may be used, as shown in figure 7-3,E. This additional pulse results in 64 different codes available in Mode 3 (as compared to the 32 codes in Mode 1). Two of these 64 available codes are used for maintenance and tests, while the remaining 62 codes are used for identification purposes. Like Mode 1, the code that contains all the information pulses and the code that contains none of the information pulses are, respectively, the maintenance and test codes—code 77 and code 00.

By knowing which pulses are present in the code train, we can identify the code that it represents in the same manner as we did with Mode 1. On the other hand, by knowing the code, we can determine which pulses are present in the code train for that code.

Mode 3 is used primarily for traffic identification. Each aircraft on a different flight schedule or mission can be assigned a different Mode 3 code. The Mode 3 code may also be different in certain areas and zones. This could require an aircraft flying cross-country to change its Mode 3 code setting several times.

Other similarities between Mode 1 and Mode 3 response codes that should be noted are:

Pulse spacing is never less than 2.9 μsec between leading edges.

- Pulses appear only at the odd-numbered pulse positions.

Exercises (484):
Refer to figure 7-3.

1. Determine pulse positions used and drawn response code train for code 53.

2. Determine pulse positions used and drawn response code train for code 77.

3. Determine pulse positions used and drawn response code train for code 10.

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485. State how Mode 2 codes differ from Modes 1 and 3 codes and state the purpose of the Mode 2 code.

Mode 2 Code. Refer to the Mode 2 code train, shown in figure 7-3,D, and note that the bracket pulse spacing is the same as for the other modes and that each pulse is 0.45 μsec wide. The pulse spacing, however, is 1.45 μsec, allowing more pulses to be present between the bracket pulses. These additional pulses make the Mode 2 code train more complex than the code trains for the other two modes.

In a Mode 2 response, as in the other modes, a pulse never appears at position 8. This divides the Mode 2 code train in half, with six information pulses and one bracket pulse on each side of the center pulse position (position 8).

If all possible combinations of the 12 information pulses were used, there would be approximately 4000 different possible codes available in Mode 2. In order to limit the number of codes used, the Mode 2 code train can contain no more than three information pulses on each side of the center. This limits the total possible number of codes available in Mode 2 to 400.

All Mode 2 codes are in letter form; that is, Mode 2 code "AB," Mode 2 code "DL," etc. Because Mode 2 codes are in letter form, it is impossible to determine which pulses are present in a code train for a specific code without the aid of a code conversion chart. Such a chart is shown in figure 7-5.

Notice in figure 7-5 that there are 20 combinations of the left pulses to provide 20 letters for the first letter of the code, and 20 combinations of the right pulses to provide 20 letters for the second letter of the code. Further examination of the figure will show that not all of the letters in the alphabet are used in the coding.

Using the Mode 2 conversion chart, determine which pulses are present in the Mode 2 code train for an RC code. The code conversion chart shows that the letter "R" is represented by pulses 2, 3, and 6, and the letter "C" is represented by pulses 9, 12, and 13. Therefore, the Mode 2 code train representing code RC consists of pulses 2, 3, 6, 9, 12, 13, and the two bracket pulses. Notice that the information pulses can appear at both even- and odd-numbered pulse positions.

There is only one Mode 2 code that has all information pulses appearing at the even-numbered positions, and only one Mode 2 code that has all the information pulses appearing at the odd-numbered positions; these are codes TW and WT, respectively. These two codes are specifically designated for maintenance and test.

Mode 2 codes are used for personal identity. A pilot may use his own initials or the initials of some VIP aboard the aircraft as the response code.

Exercises (485):

1. State how Mode 2 codes are different from Modes 1 and 3 codes.
2. What is the purpose of the Mode 2 code?
3. Refer to figure 7-5 and determine what pulses are present for a TS code.

486. List the special responses available and state the purpose of each.

Special Responses. A pilot may respond to a Mode 1 or a Mode 3 interrogation with a special response known as I/P (identification of position). Unlike the I/P response in basic IFF, which is a double-pulse reply, the I/P response in IFF/SIF is two complete Mode 1 or Mode 3 code trains for each interrogation of the aircraft. The two complete code trains are separated by 4.35 μsec.

An emergency response can also be made by the pilot when the aircraft is being interrogated in Mode 1 or Mode 3. The emergency reply consists of four complete Mode 1 or Mode 3 code trains for each interrogation. Each code train in the emergency reply is separated by 4.35 μsec.

Exercises (486):

1. List the special responses available.
2. State the purpose of each response.

The IFF/SIF PPI presentations are most important to the operator who must use them while controlling and monitoring aircraft traffic. Here, we will discuss the several possible IFF/SIF presentations that the operator may select to view on his PPI scope.

487. Draw an indicator showing the types of IFF/SIF responses available, label each response, and state the use of a specified response.

Presentation of IFF/SIF Responses. The IFF/SIF responses, after being processed by the decoders, are available at the decoder output as either decoded video, raw video, or beacon video. The radar operator, by controlling the output of the decoder, determines which video is presented on the radar indicator. All

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LEFT PULSES	PULSE POSITION NUMBERS						RIGHT PULSES	PULSE POSITION NUMBERS					
A	2	3	4				A	9	10	11			
B	2		4	5			B	9		11	12		
C	2			5	6		C	9			12	13	
D	2				6	7	D	9				13	14
E		3	4	5			E		10	11	12		
F		3		5	6		F		10		12	13	
G		3			6	7	G		10			13	14
H			4	5	6		H			11	12	13	
K			4		6	7	K			11		13	14
L	2	3				7	L	9	10				14
M		3	4			7	M		10	11			14
N			4	5		7	N			11	12		14
O				5	6	7	O				12	13	14
P		3	4		6		P		10	11		13	
R	2	3			6		R	9	10			13	
S	2	3		5			S	9	10		12		
T	2		4		6		T	9		11		13	
V	2			5		7	V	9			12		14
W		3		5		7	W		10		12		14
Z	2		4			7	Z	9		11			14

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Figure 7-5. Code conversion chart.

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normal responses, regardless of mode, appear as single arcs on the radar indicator. I/P responses appear as two arcs, and emergency responses appear as four arcs. Figure 7-6 shows the IFF/SIF responses.

The radar operator may select raw video (the switch is labeled RAW-OFF BRKT) for presentation on the radar indicator. Raw video is undecoded video; that is, each pulse contained in the code-train response is presented on the radar indicator. This is seen on the indicator as one arc for each pulse contained in the code train.

Any IFF/SIF response, regardless of mode, must contain bracket pulses. The decoders reduce the bracket pulses to a single pulse known as the beacon pulse. The beacon pulse, when it is selected by the operator, causes a single arc presentation on the indicator. This assures the radar operator that the aircraft is responding with an IFF/SIF response, although the operator is unable to determine the mode or code of the response. In order to prevent misinterpretation of the beacon pulse from a Mode 1 or Mode 3 reply (both are seen as a single arc on the indicator), a beacon assist switch is located on the operator's control unit. When it is operated, the bracket pulses are widened, and, therefore, the spacing of the beacon response is viewed on the indicator. Since this affects only the bracket pulses, normal Mode 1 or Mode 3 replies are distinguishable from the wide beacon pulse.

Exercises (487):

1. Draw a PPI indicator with the IFF/SIF responses and label each.

2. How can an operator know an aircraft is responding when he is unable to determine the mode or code of the response?

7-3. Coder-Interrogator

The coder-interrogator provides the paired-pulse interrogation codes that are needed to modulate the IFF transmitter in order to interrogate an aircraft. A functional block diagram of the coder-interrogator is shown in figure 7-7.

488. List the four major operations performed by the coder-interrogator, and state the purpose of the interlacing modes.

An input trigger from the associated radar system is applied to the reference multivibrator, which assures that the SIF trigger frequency does not exceed 400 PPS. The reference multivibrator output trigger is then applied, through the adder network and delay line amplifier, to the code generator delay line and pulse amplifiers. This block produces three pulse modes: Mode 1, Mode 2, and Mode 3. The reference multivibrator output trigger is also applied to the interlace multivibrator and to the mode selector matrix network. If interlaced modes are selected, the interlace multivibrator provides triggers to use two modes alternately by switching the gates that are fed from the mode selector matrix network.

The desired operating mode is affected by the gating circuits that are selected by the mode selector switch on the coder-decoder control. The mode selector switch controls the mode selector matrix network, which also receives inputs from the reference multivibrator, adder network, and interlace multivibrator. The mode selector matrix routes its output to the appropriate mode-gating multivibrators, which, in turn, gate corresponding mode trigger amplifiers and the code pulse selector circuits in the code generator delay line. The outputs of the three mode trigger amplifiers are sent to the video decoder to enable appropriate mode-decoding circuits.

The code generator delay line receives a trigger input from the reference multivibrator, feeding through the adder network and the delay line amplifier, and a gate input from the mode-gating multivibrators. The outputs of the code generator delay line and pulse amplifier circuits feed to the display trigger pulse generator for an auxiliary video display, when necessary; but, more important, the code generator delay line and pulse amplifiers provide the signals for the interrogation code pulse generator.

Exercises (488):

1. Write the four functions of the coder-interrogator.

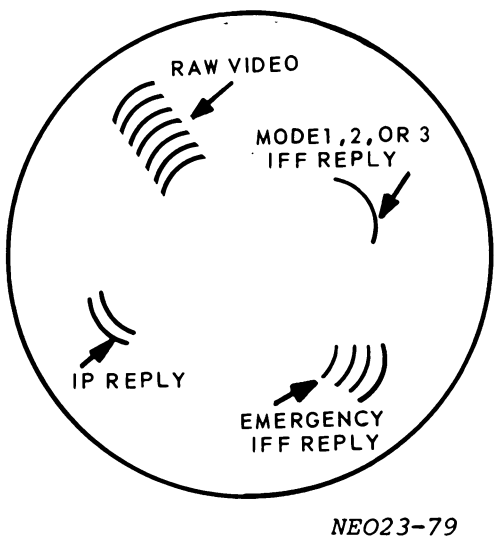

Figure 7-6. Typical PPI display, showing responses from decoder.

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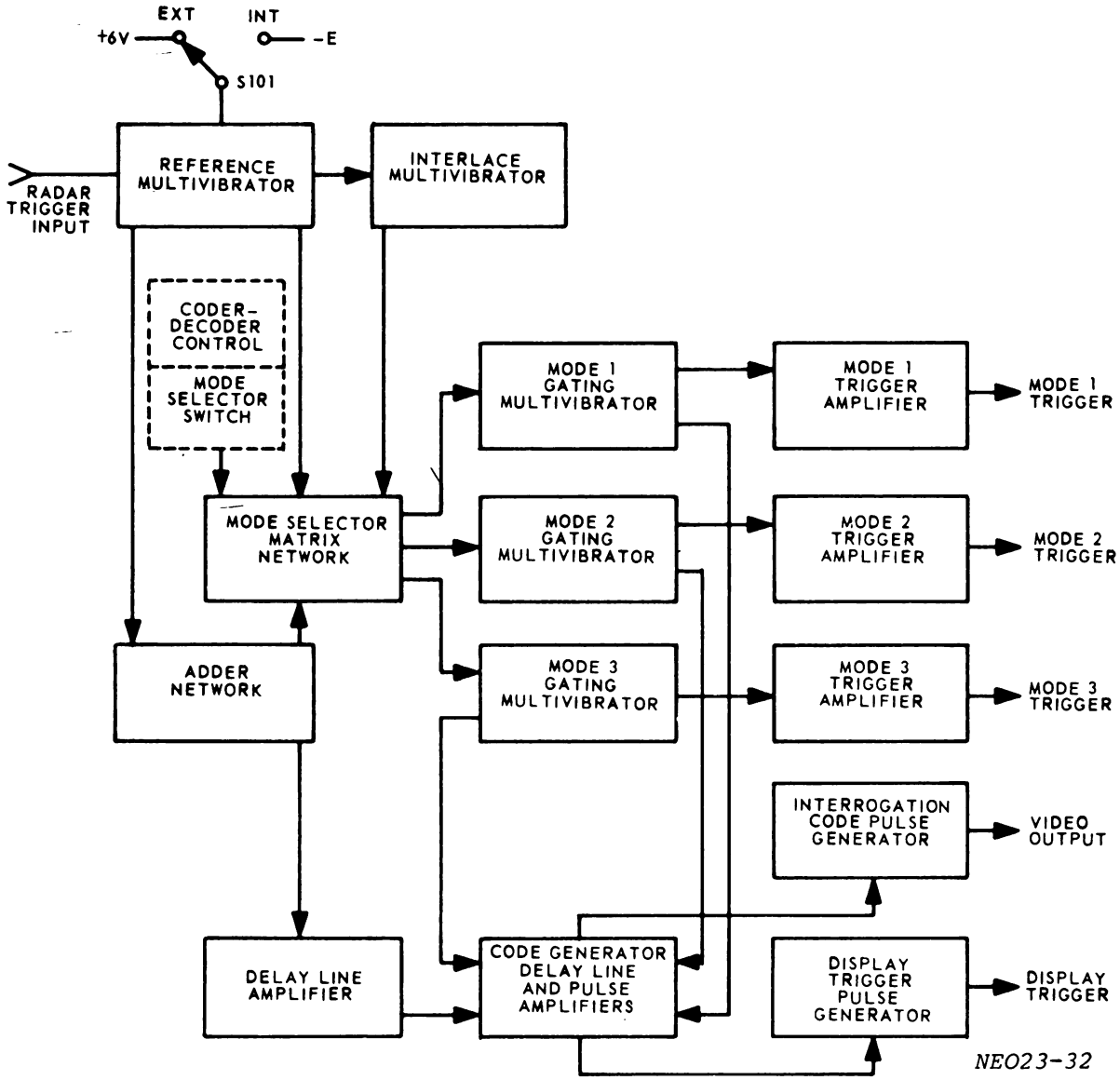

Figure 7-7. Coder-interrogator, block diagram.

2. What is the purpose of interlacing modes?

7-4. Video Decoder

The video decoder, which is the second component of the coder-decoder group, provides the decode capability required to complete the IFF/SIF operation. The resultant decoded video is applied to the PPI indicator.

489. List the possible outputs from the video decoder and describe the function of each output.

When the ground station challenges an aircraft, causing the aircraft transponder to send a coded reply, we must *decode* the reply in order to determine the status of the aircraft. A typical decoder contains a delay-line system (similar to the one in the coder-interrogator) and code selection circuits to determine whether a right or wrong reply is received from the aircraft. It also contains gate circuits that pass only the right codes, beacon-assist circuits to widen the received pulses when desired, and mixer circuits to combine all of the outputs of the video decoder into a common video signal.

A functional block diagram of the video decoder is shown in figure 7-8. Inputs to the decoder include the IFF video and the mode triggers from the coder-interrogator. Outputs include decoded video, decoded

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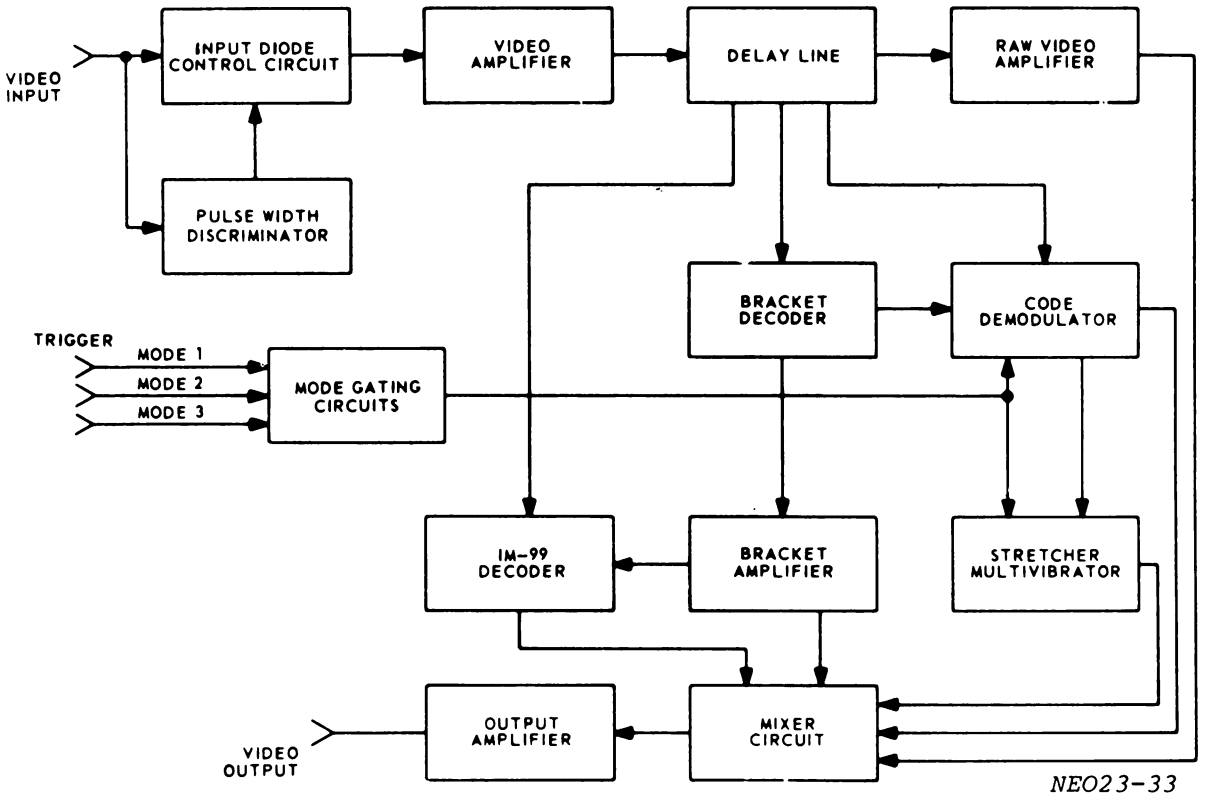

Figure 7-8. Video decoder.

bracket video, or raw video, at the operator's discretion. The input diode control circuit and pulse-width discriminator operate in normal or ECM modes to develop positive signals, which feed through the video amplifier to the delay line. If the code train is required for viewing as received, all of the responses in the delay line feed through the raw video amplifier, mixer circuit, and output amplifier to the video output. This output is called *raw video* and shows the operator what code the aircraft is sending.

The three mode triggers from the coder-interrogator (fig. 7-7) are applied to the mode-gating circuits to provide gates for the code demodulator. This allows only the responses of the interrogation mode to be decoded. This decoded video output indicates that the correct code was received. The code demodulator determines whether or not the code-train response corresponds to the interrogation mode sent by the coder-interrogator. Right- and wrong-code detectors use switching circuits and delay lines to select the proper response. If a beacon assist is necessary, bracket or stretched pulses can be used for each correctly coded response to indicate the aircraft is responding.

Exercises (489):

1. What are the outputs of the video decoder?
2. Describe the function of each output.

7-5. Performance Testing

The IFF/SIF system must be checked, aligned, and adjusted, using applicable technical orders. Always be cautious while performing alignments and adjustments on the IFF/SIF system. There are high DC voltages which have to be measured and adjusted. These checks and adjustments will be performed while the equipment is on and equipment covers removed.

490. List the checks that can be performed on the IFF/SIF system, and indicate the meaning of specified check results.

After the required alignments and adjustments are completed, there are some operational checks that should be done. If there is an aircraft in the area, use him to provide the required IFF/SIF responses. If there is no aircraft, you will have to use local test equipment to simulate an aircraft reply. This test equipment must be operated according to the current technical orders.

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We are going to use an aircraft for a check, so be sure the associate radar is ON and furnishing pretriggers for the IFF/SIF system (see fig. 7-1), and that the PPI indicator is functioning. Check to see that all power switches and time delays are completed in the IFF/SIF system. Select a Mode 1 code and turn on the challenge switch. The challenge light should come ON. This indicates that you are developing interrogation pulses. Select raw video and be sure that the receiver gain is normal. The aircraft, if his transponder is on, should reply and this reply will appear on the PPI as a series of arcs. Adjust the IFF/SIF and PPI gains for best presentation. To check the decoder, place the RAW-OFF-BRKT switch to the OFF position and turn the Mode 1 code-selecting controls through all its positions. The correct code will appear as a single arc in place of the previous raw video (see fig. 7-6).

Exercises (490):

1. List checks that can be performed on the IFF/SIF system.

2. What does the challenge light being ON indicate?

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Answers For Exercises

CHAPTER 1

Reference:

400 - 1. See figure 1-1.
400 - 2. Power supply furnishes all AC and DC voltages; transmitter generates high-power RF; antenna radiates transmitter energy and receives reflected energy; receiver amplifies received echoes and changes them to video; indicator displays range, azimuth, or elevation of received targets; and the synchronizer times the operation of all units.

401 - 1. Radar waves are transmitted, reflected, and controlled the same as light and sound waves.
401 - 2. No.
401 - 3. Can be controlled in duration and direction; are reflected when they strike an object; and travel at a constant velocity.
401 - 4. 12.36.
401 - 5. Azimuth and elevation.
401 - 6. In degrees.
401 - 7. Measures the time between the transmitted and reflected pulses.

402 - 1. 1.-c, 2.-b, 3.-a, 4.-b, 5.-a, 6.-c.

403 - 1. Conical scan.
403 - 2. Conical scan.
403 - 3. Monopulse.
403 - 4. Monopulse.
403 - 5. Monopulse.

404 - 1. Convert range, azimuth, and elevation information for display on the plotting board and solve ballistic problems.

405 - 1. To provide the radar operator with the identification and location of friendly aircraft.
405 - 2. In congested flying areas.

CHAPTER 2

406 - 1. 1.-f, 2.-b, 3.-e, 4.-a, 5.-d, 6.-c, 7.-g.

407 - 1. a. Reduced to one-third its previous value.
b. Reduced to one-third its previous value.
c. Increased three times.
407 - 2. 169.6 yards.
407 - 3. A 0.18-microsecond pulse.

408 - 1. a. 8, ;b. 4, c. 5, d. 3, e. 6, f. 2, g.7, h. 1.
408 - 2. Normally, a one-to-one relationship.
408 - 3. In the pulse-shaping circuit.
408 - 4. The directional coupler.

409 - 1. To provide a discharge path for the PFN.
409 - 2. Stores large amounts of energy during the interval between triggers.
409 - 3. To double the applied voltage to the PFN.

410 - 1. False.
410 - 2. False.
410 - 3. True.
410 - 4. False.
410 - 5. True.

411 - 1. Increase the capsule voltage.
411 - 2. Flashing and arcing of the ionized gas.

412 - 1.

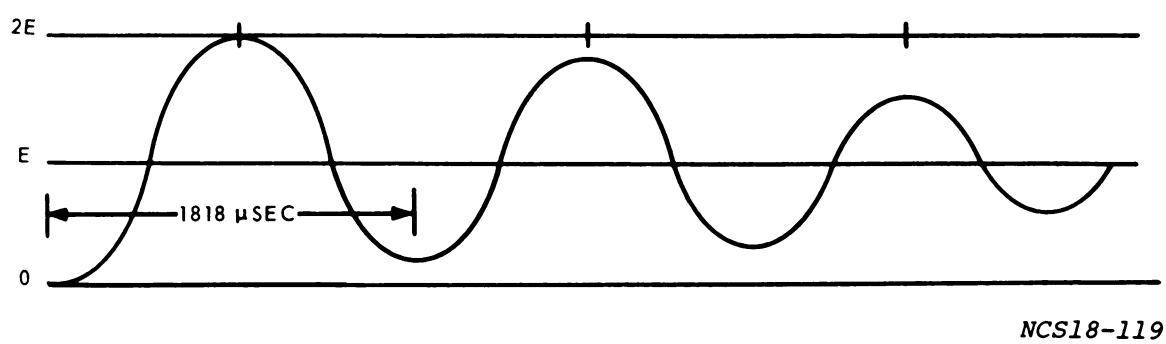

Figure 1. Untriggered PFN charging waveforms (answer for objective 412, exercise 1).

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412 - 2.

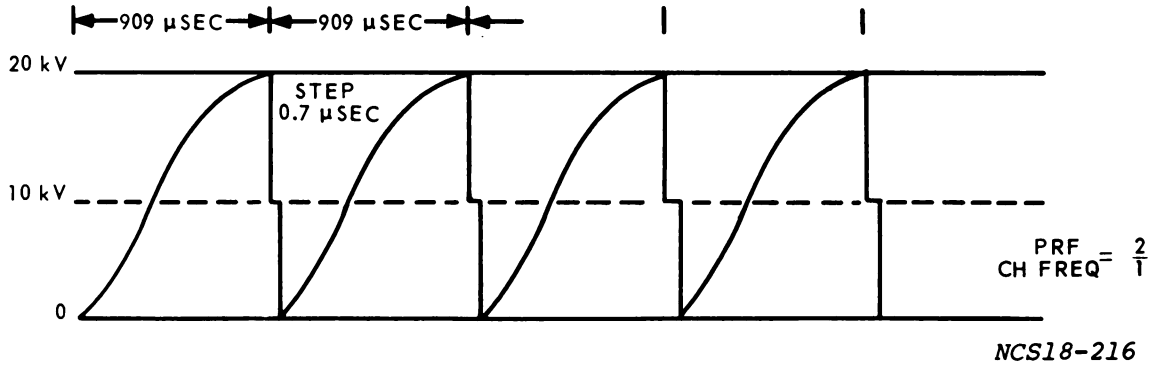

Figure 2. Triggered PFN waveform (answer for objective 412, exercise 2).

413 - 1. It prevents the PFN from developing a negative charge.
413 - 2. It allows the PFN to reach twice the supply voltage.
413 - 3. It determines the slope of the voltage pulse.
413 - 4. The high-amplitude spike would form at the leading edge that would probably cause magnetron arcing.

414 - 1. It shapes and amplifies the pulse.
414 - 2. The power supply.
414 - 3. It delays the firing of the magnetron to compensate for trigger delays in other circuits which must coincide with the firing of the transmitter.
414 - 4. It acts as a switch.

415 - 1. The size (reactive properties) of the anode block cavities.
415 - 2. A process of connecting specific cavities to cause them to function in a definite phase relationship.
415 - 3. By reducing the filament voltage.
415 - 4. Preventing contact between the magnet and ferromagnetic materials.

416 - 1. Zero.
416 - 2. Prevent the buildup of a large voltage across the secondaries of T3.
416 - 3. a.3, b.1, c.4, d.2.

417 - 1. 1.c, 2.e, 3.d, 4.a, 5.b, 6.f, 7.g.

418 - 1. It routes the RF to the antenna by blocking the alternate path to the receiver.
418 - 2. It guides echo pulses to the receiver.
418 - 3. It is maintained just below its ionizing point by the keep-alive voltage.

419 - 1. a. Circulator.
b. Branched duplexer.
419 - 2. + 135°.
419 - 3. After the TR tube has deionized.
419 - 4. It has no function during transmit time.

420 - 1. a. Dipole feed Cassegrain.
b. Cassegrain.
c. Dipole feed.
d. Dipole feed.
e. Cassegrain.
f. Dipole feed.

421 - 1. a. The simplest performance tests are observations of panel indicators.
b. Test points are provided to conduct performance measurements using external test equipment.
c. Preventive maintenance procedures are important for dependable operation.
d. Most transmitter alignments are done routinely.
421 - 2. a. High-voltage power supply.
b. Thyratron capsule voltage.
c. Overcurrent relay.
d. Magnetron filament voltage.
e. Magnetron frequency.

422 - 1. The increased RF level near resonance causes the rectified DC on the meter to increase. After passing through resonance, the voltage would decrease.
422 - 2. The power output of the transmitter has probably decreased.

423 - 1. Connect the echo box. Tune the echo box for peak-meter reading. Read the echo box frequency dial.
423 - 2. Reset the echo box dial to the desired frequency. Tune the magnetron for maximum echo box meter reading.

424 - 1. It doubles (example, 10 dBm = 10 mW, 13 dBm = 20 mW).
424 - 2. 3 × 15 + 5 = 50 dBm, 50 dBm = 100 watts.
424 - 3. It will decrease about 6 dB.
424 - 4. The measurement in watts is multiplied by a factor of 10.

425 - 1. 0 milliwatts.
425 - 2. Resetting the zero adjust for a 0-milliwatt reading will balance the bridge by increasing the resistance of the thermistor.
425 - 3. The resistance of the thermistor is reduced, which unbalances the bridge and causes current to flow through the meter in proportion to the change.

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426 - 1.

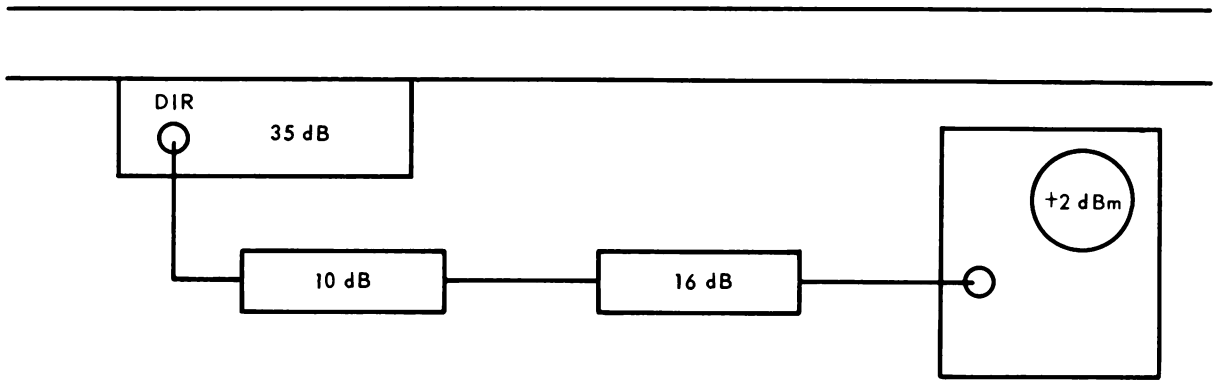

Figure 3. Thermistor bridge test connections (answer for objective 426, exercise 1).

426 - 2. +63 dBm.
426 - 3. 2 kilowatts.

427 - 1. The transmitter's power output is probably the same.
427 - 2. Check the transmitter with a power meter.

428 - 1. Measure transmitted power by connecting a thermistor bridge power meter to the direct jack on the directional coupler. Measure reflected power by connecting the power meter to the reflected jack of the directional coupler.

429 - 1. 55 dBm.
429 - 2. 39 dBm.
429 - 3. Approximately 1.4.
429 - 4. Yes.

430 - 1. (a) 2800 MHz; (b) 2801 MHz; (c) 2801.5 MHz.
430 - 2. 15 MHz.

431 - 1. Two identical spectra will be observed, one 22.5 MHz below the oscillator frequency and the other 22.5 MHz above.
431 - 2. Move the frequency meter pip along the baseline until it is centered on the upper sideband and record the frequency meter reading. Repeat this for the lower sideband. Then subtract the lowest reading from the highest. The difference is the bandwidth.

432 - 1. The spectrum would probably show evidence of missing pulses caused by intermittent misfiring of the magnetron. Average power would be reduced in proportion to the number of missing pulses.
432 - 2. The rotary joint is probably worn or off-centered.

433 - 1. Connect the echo box to the directional coupler. Tune through the transmitter range in small increments. Plot the echo box meter readings on a graph and connect the plotted points.

434 - 1. The probe meter movement contains no permanent magnet. It is the magnet under test.
434 - 2. The gaussmeter contains the same parts but has a retarded zero that prevents reaction to current levels below 1 milliampere.
434 - 3. They are in series.

435 - 1. Gain access to the poles of the magnet. Insert the probe meter into the gap between magnet poles. Calibrate the fluxmeter.

436 - 1. 1600 gauss.

437 - 1. (a) Storage practices—proximity to steel objects reduces flux level. (b) Handling—mechanical shock reduces magnet strength. (c) Installation—contact with steel tools reduces magnet strength.

438 - 1. False.
438 - 2. True.
438 - 3. False.
438 - 4. True.

439 - 1. (a) A crack in the glass shell or ceramic window will result in loss of vacuum. (b) Damage to the anode block can cause undesirable changes in output frequency or defects in the tuning assembly. (c) Impact may cause a cathode-to-anode short within the magnetron.

440 - 1. Check the trigger into and out of the trigger amplifier.
440 - 2. An interlock in the high-voltage circuit is probably open.
440 - 3. Substitute a *known good* tube for the questionable one.
440 - 4. By applying the output to a high-voltage breakdown test set.

441 - 1. A split spectrum indicating double noding.
441 - 2. In the rotating joint.

442 - 1. c, d, and e.

443 - 1. Apply an RF pulse from a signal generator. Adjust it for a 1-inch aplitude below the receiver limit level. Move it toward the main bang until it decreases to 0.7 volt, then measure the time interval between pulses.
443 - 2. 0.7 volt is the point at which the test pulse has lost one-half its strength in the TR.

444 - 1. Attenuation of magnetron power by corrosion in the waveguide.
444 - 2. The dummy load.

CHAPTER 3

445 - 1. Noise, gain, tuning, and distortion.
445 - 2. Noise.
445 - 3. Distortion.
445 - 4. The type of indicator system used.

446 - 1. 1. d; 2. g; 3. a; 4. b; 5. f; 6. c.

447 - 1. 1. b; 2. d; 3. a; 4. c; 5. e.

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448 - 1. Local oscillator output and the receiver RF signal.
448 - 2. Heterodyne principle.
448 - 3. Its noise suppression capability.
448 - 4. The balance between the crystals.

449 - 1. Provide a continuous-wave RF signal to the signal mixer.
449 - 2. 3025 MHz.
449 - 3. It is a continuous-wave, sinusoidal, constant level, noise-free signal.
449 - 4. Manual tuning is by varying the size of the cavity and automatic tuning is by varying the negative potential on the repeller plate.

450 - 1. 5 MHz.
450 - 2. -30 volts.
450 - 3. To insure that the local oscillator locks on to a frequency 60 MHz above the received RF signal.
450 - 4. Tracking, searching, and feedback bias.

451 - 1. To improve the signal-to-noise ratio and provide high gain.
451 - 2. Further amplify the IF signal and detect the video.
451 - 3. The first two stages.
451 - 4. First three stages of the IF amplifier and the final stage of the IF preamplifier.
451 - 5. Automatic gain control (AGC) and manual gain control (MGC).

452 - 1. Fast-time constant (FTC) and sensitivity time constant (STC).
452 - 2. Fast-time constant (FTC).
452 - 3. By the setting of the STC control.

453 - 1. To amplify and improve the shape of the video.
453 - 2. Delayed and nondelayed video.
453 - 3. Video pulses from the IF amplifier.

454 - 1. AGC channel and lobing error channel.
454 - 2. Furnish automatic gain control for the IF channel and a signal for the antenna-positioning system.
454 - 3. Nondelayed video, gated video, and the clear-out pulse.
454 - 4. Automatic.
454 - 5. Threshold.

455 - 1. 1. b, 2. d, 3. c, 4. a.
455 - 2. Manually.
455 - 3. Beacon delay.
455 - 4. Aircraft transponder.

456 - 1. Minimum discernible signal (MDS) and noise figure (NF).
456 - 2. The ability of a receiver to pick up weak signals.
456 - 3. Signal generator for MDS and noise generator for NF.
456 - 4. By taking the readings with the signal generator in different locations and comparing the readings.
456 - 5. Ready.
456 - 6. Negative dBm.
456 - 7. Equal to the noise being generated within the receiver.

457 - 1. Time required for receiver sensitivity to return to within 6 dB of normal after the end of the transmitter pulse.
457 - 2. Pulsed signal generator or a CW signal generator.
457 - 3. Microseconds, miles, or yards.

458 - 1. The frequency spread between the half-power points on the receiver response curve.
458 - 2. FM signal generator.
458 - 3. 3 dB.
458 - 4. No material effect.

CHAPTER 4

459 - 1. Delay the sync and preknock pulses.
459 - 2. Determine the operating frequency of the radar.
459 - 3. Delay sync pulse with respect to preknock.
459 - 4. During calibration and alignment.

460 - 1. The output of the coincidence stage occurs 48.8 μsec before the modulator trigger.
460 - 2. 1.6 μsec.
460 - 3. 82-kHz reference pulse and 410-Hz reference gate.
460 - 4. 82-kHz phased and 410-Hz phased gate.
460 - 5. Track gate, because it is developed in the reference chain.

461 - 1. Synchroscope or oscilloscope.
461 - 2. Present a high-input impedance.
461 - 3. The characteristics of the waveform to be measured.
461 - 4. Input frequency response, input impedance, sensitivity, and sweep speeds required to test the waveforms.

462 - 1. Furnish the trigger to the track range computer.
462 - 2. Produce the track range mark.
462 - 3. Converts the DC range error to a 400-Hz error signal.
462 - 4. Compare the range gate and return video and develop the DC error signal if they don't have a proper relationship.
462 - 5. Range preknock occurs 11 to 69 μsec prior to the sync pulse.

463 - 1. Positive gate to the phantastron and a negative gate to the timing-wave generator.
463 - 2. Your waveshape should resemble waveshape d.
463 - 3. The leading edge of the selected gate.
463 - 4. 36 μsec.
463 - 5. The selected pip occurs 12.36 μsec prior to the track range mark.

464 - 1. 400 Hz whose amplitude is determined by the speed the handwheel is turned and whose phase is determined by the direction.
464 - 2. 400 Hz taken from the wiper arm. The amplitude is determined by the speed the handwheel was turning while the clutch was engaged and the phase by the direction of rotation.
464 - 3. 400 Hz whose amplitude is determined by the separation between the range gate and target and whose phase is determined by whether the target is closer or farther away than the range gate setting.
464 - 4. The range handwheel.

465 - 1. Synchronizer.
465 - 2. Range servoamplifier.
465 - 3. Control panel.
465 - 4. *On target.*
465 - 5. *Range* and *target.*

466 - 1. Generate an error voltage proportional to the distance between the center of the target and the center of the track gate.
466 - 2. Pulse splitting.
466 - 3. Modulator trigger, track gate, and ungated IF.
466 - 4. A DC error voltage proportional to the range error.
466 - 5. The target must be within the track gate.

467 - 1. Synchronizer, transmitter, receiving systems, and power supplies.
467 - 2. Stationary target.
467 - 3. The target should automatically return to the center of the range gate.

CHAPTER 5

468 - 1. Your figure should resemble figure 5-1.
469 - 2. Your figure should resemble figure 5-2.
468 - 3. Your figure should resemble figure 5-3.
468 - 4. It has a very wide beamwidth and a dual radiation pattern.
468 - 5. It has a very wide beamwidth.

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468 - 6. It has a very narrow beamwidth and a high gain.
468 - 7. Increases.
468 - 8. A nutating mechanism.
468 - 9. Decibles.
468 - 10. Dipole with a parabolic.

469 - 1. By the nutating action of the radiating dipole.
469 - 2. Conical scanning.
469 - 3. 30 Hz.
469 - 4. The amount the antenna is off target.
469 - 5. The error signal is zero.
469 - 6. Azimuth and elevation error.

470 - 1. Produce two voltages 90° out of phase for comparison with the 30-Hz envelope of the RF return signal.
470 - 2. Increase the gain of the azimuth channel as the elevation angle increases.
470 - 3. Shift the phase of the outputs of the reference generator as the range increases.
470 - 4. 90° out of phase with each other.
470 - 5. The amplitude of the error signal decreases.
470 - 6. High elevation angles.
470 - 7. Steps proportional to the secant of the elevation angle.

471 - 1. 1. a, 2. c, 3. b, 4. d, 5. c, 6. a.

472 - 1. 1. b, 2. c, 3. e, 4. h, 5. d, 6. f, 7. g, 8. a.

473 - 1. The synchronizing system, transmitting system, and receiving alignments.
473 - 2. These alignments require you to work at the antenna pedestal with power applied. This condition requires that an individual familiar with the work being accomplished monitor the controls to insure that the antenna is not moved except when you direct its movement.

CHAPTER 6

474 - 1. Electrostatic and electromagnetic.
474 - 2. Replacement of the focusing anode and deflection plates in the electrostatic CRT with focus coils and deflection coils in the electromagnetic CRT.
474 - 3. The magnetic field lines of force of the focus coil cause the individual electrons to complete a portion of a helical turn within the limits of the field.
474 - 4. By the magnetic field set up by the current flow through the deflection coils. The coils are placed so that it is a push-pull deflection.

475 - 1. Your drawing should resemble figure 6-3.
475 - 2. By simultaneously applying sawtooth voltages 180° out of phase with each other to the horizontal deflection plates.
475 - 3. By simultaneously applying the video in phase to the vertical deflection plates.

476 - 1. Your drawing should resemble figure 6-4.
476 - 2. The range sweep is a vertical trace synchronized to the transmitter trigger while the angle sweep is a horizontal trace synchronized to the RF beam motion.
476 - 3. Range is read on the vertical with the bottom of the scope being zero yards. Angle is read on the horizontal with 20° either side of the centerline.

477 - 1. Your drawing should resemble figure 6-5.
477 - 2. By applying two sine waves, 180° out of phase, to the horizontal deflection plates. This voltage is also applied to the vertical deflection plates, 180° out of phase with each other and 90° out of phase with the signals applied to the horizontal plates.
477 - 3. Negative video is applied to the anode of the CRT.

478 - 1. 400-KYD, 40-KYD, and 2-KYD displays.
478 - 2. *400-Kyd scope* has the following inputs: 410-Hz sweep drive from the synchronizer, IF input from the receiver.
40-Kyd scope has the following inputs: IF input from the receiver, 4100-Hz sweep drive from synchronizer, 40-Kyd unblanking gate from synchronizer, track gate from synchronizer.
2-Kyd scope has the following inputs: IF input from the receiver, 2-Kyd unblanking gate from synchronizer, N^2 gate from synchronizer, 82-kHz sweep drive from synchronizer.

479 - 1. Your figure should resemble figure 6-7.
479 - 2. Applying a sawtooth waveform to the deflection coils.
479 - 3. By applying a modulating carrier to the deflection coils.

480 - 1. 1. m, 2. n, 3. l, 4. e, 5. h, 6. f, 7. g, 8. d, 9. b, 10. a, 11. c, 12. i, 13. j, 14. k, 15. o, 16. p, 17. q.

481 - 1. Synchronizer and range indicator power supplies, crystal oscillator, and frequency dividers.
481 - 2. Extreme high voltage exists within these units.

CHAPTER 7

482 - 1. 1. d, 2. f, g, h, 3. c, 4. e, 5. a, 6. b.

483 - 1. 61.
483 - 2. 42.
483 - 3. 70.

484 - 1. A1, A4, B1, B2. Refer to figure 7-3 for drawing of code-train responses.
484 - 2. A1, A2, A3, B1, B2, B3. Refer to figure 7-3 for drawing of code-train responses.
484 - 3. A1. Refer to figure 7-3 for drawing of code-train responses.

485 - 1. Mode 2 has 400 different codes, Mode 2 codes are in letter form.
485 - 2. Use for personal identity.
485 - 3. 2, 4, 6, 9, 10, 12.

486 - 1. I/P response, emergency response.
486 - 2. I/P response shows the aircraft's position; emergency response shows he has a problem.

487 - 1. Check your drawing against figure 7-6.
487 - 2. He can select beacon.

488 - 1. a. Acts as the mode selector unit.
b. Produce a set of coded output pulses.
c. Interlaced transmission of modes 1 and 3, modes 2 and 3 or modes 1 and 2.
d. Gate incoming video so that only the operating mode video is displayed on the radar PPI.
488 - 2. Allows two radar operators to simultaneously challenge more than one aircraft in different modes.

489 - 1. Decoded video, decoded bracket video, raw video.
489 - 2. a. Decoded video indicates the correct code was received.
b. Decoded bracket video indicates the aircraft is responding.
c. Raw video tells the operator what code the aircraft is sending.

490 - 1. Power lights on, challenge lights on, and IFF video is displayed on the PPI in raw video position. Turn RAW-OFF-BRKT to OFF position and rotate mode control until correct code video appears on the PPI.
490 - 2. The recognition set is developing interrogation pulses.

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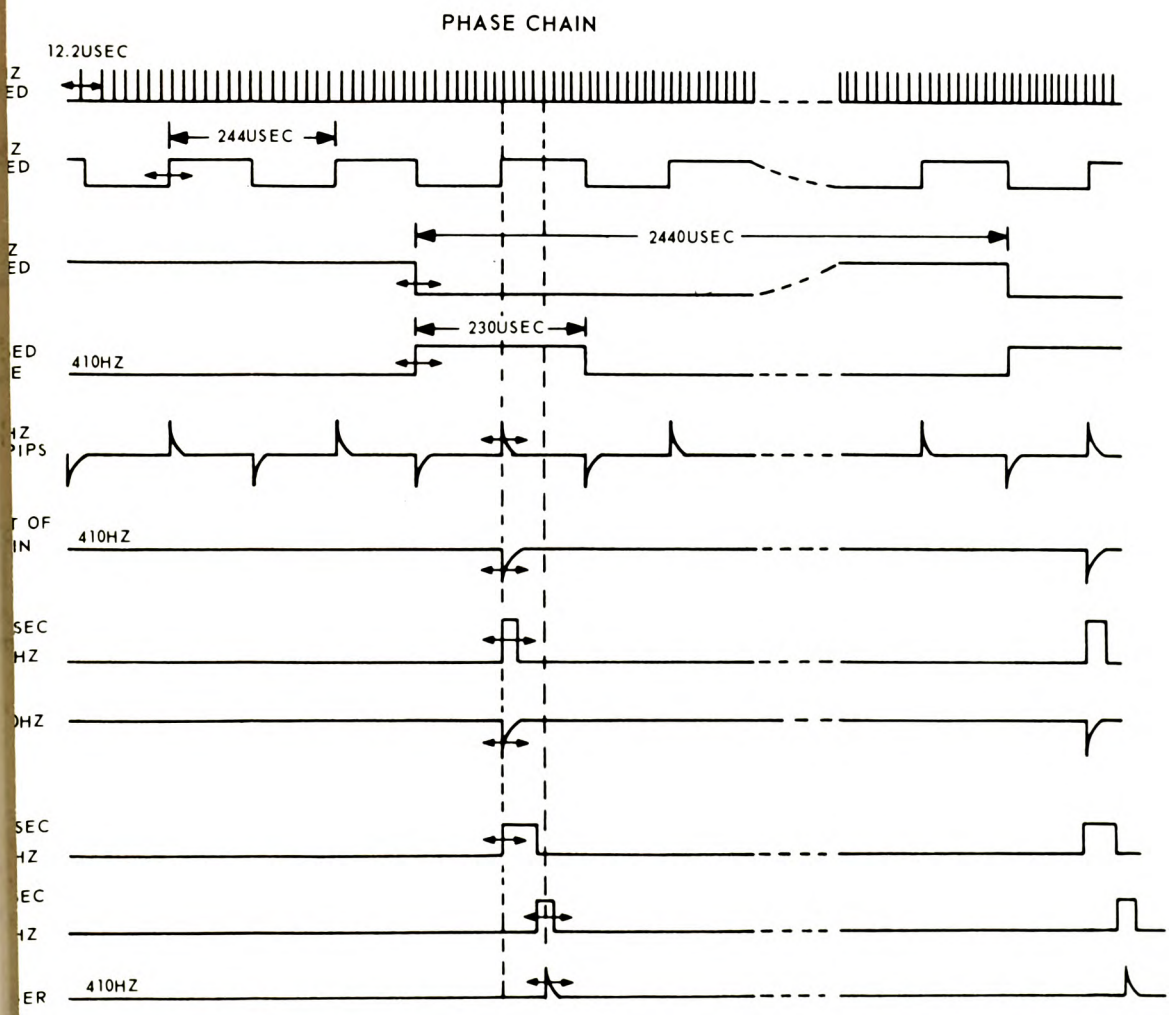

Foldout 1. Synchronizer block diagram and waveforms.

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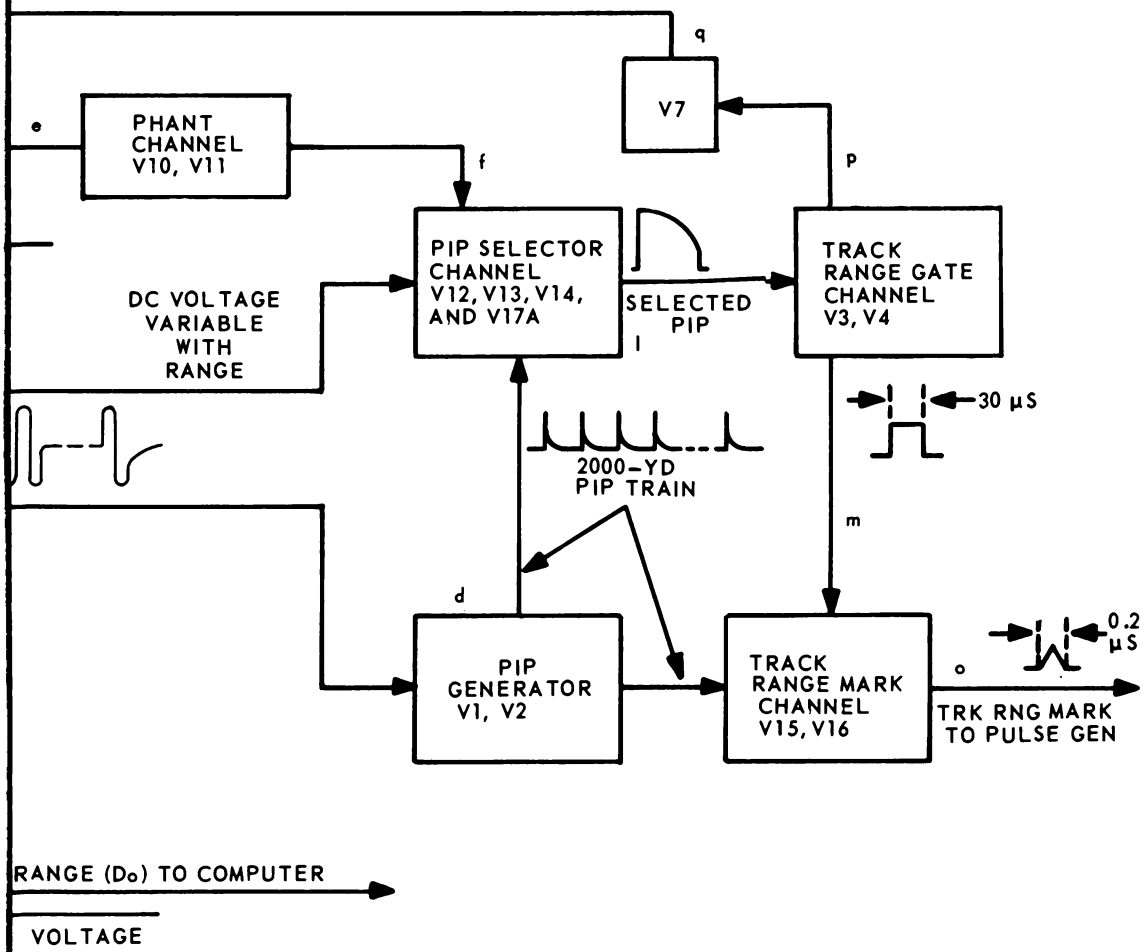

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Foldout 2. Track range computer block diagram.

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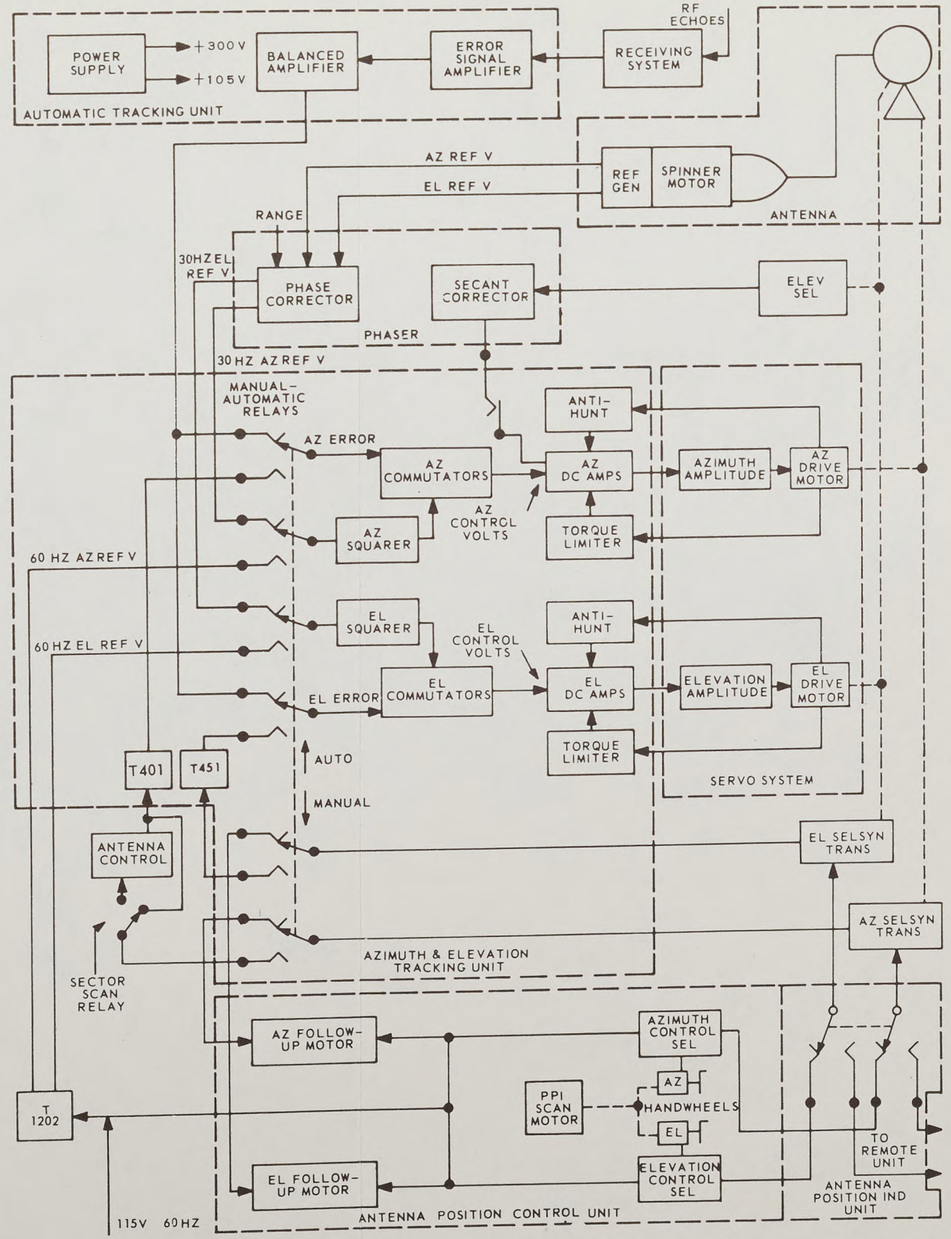

Foldout 3. Antenna-positioning system.

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wils.gov
D 301.26/17-2:30353 03 7705
Mitzel, William F.
Automatic tracking radar repairman (AFSC
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